IN THE MATTER OF

PATENT APPLICATION

CERTIFICATE

I, So ISHIBASHI, residing at 2-20-25-303, Kamishinden, Toyonaka-shi, Osaka 560-0085 Japan, hereby certify that I am well acquainted with the English and Japanese languages and that the document attached hereto is a translation made by me of the Japanese Patent Application Number 10-264849 and certify that it is a true translation to the best of my knowledge and belief.

Dated this 25th day of April, 2007

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[Title of the Invention] Liquid crystal display apparatus

[Claims]

[Claim 1] A liquid crystal display apparatus comprising: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material, characterized in that each of the linear wall structures comprises a plurality of constituent units.

[Claim 2] The liquid crystal display apparatus of claim 1, characterized in that the constituent units of the linear wall structures have a substantially uniform shape and are divided from each other by a change in shape or cutting.

[Claim 3] The liquid crystal display apparatus of claim 1, characterized in that the constituent units of the linear wall structures of the two substrates extend parallel to each other.

[Claim 4] The liquid crystal display apparatus of claim 1, characterized in that the constituent units of the linear wall structures of the two substrates extend parallel to each other and are shifted from each other.

[Claim 5] The liquid crystal display apparatus of claim 1, characterized in that the constituent units of the linear

wall structures of each said substrate have different lengths.

[Claim 6] The liquid crystal display apparatus of claim 1, characterized in that the constituent units of the linear wall structures of each said substrate are spaced apart from each other, and the constituent units of the linear wall structures of one of the two substrates are located between the constituent units of the linear wall structures of the other substrate.

[Claim 7] The liquid crystal display apparatus of claim 1, comprising: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material, characterized in that the linear wall structures of at least one of the two substrates include: means for forming a boundary of alignment of a first type in which liquid crystal molecules surrounding a point are directed to the point; and means for forming a boundary of alignment of a second type in which some of liquid crystal molecules surrounding a point are directed to the point and the other liquid crystal molecules surrounding the point are directed away from the point, and that the means for forming the boundary of alignment of the first type is provided

within the constituent units.

[Claim 8] The liquid crystal display apparatus of claim 7, characterized in that each of the linear wall arranged structures comprises a plurality of constituent units, and the means for forming the boundary of alignment of the second type is arranged in the boundary between the constituent units.

[Claim 9] The liquid crystal display apparatus of claim 8, characterized in that in each of the linear wall structures, the means for forming the boundary of alignment of the first type and the means for forming the boundary of alignment of the second type are arranged alternately.

[Claim 10] The liquid crystal display apparatus of claim 7, characterized in that one of the two substrates includes a pixel electrode, one of the boundaries of the linear wall structure on the one substrate, which is closest to an edge of the pixel electrode, defines a boundary of alignment of the second type, and one of the boundaries of the linear wall structure on the other substrate, which is closest to the edge of the pixel electrode, defines a boundary of alignment of the first type.

[Claim 11] The liquid crystal display apparatus of claim 7, characterized in that at least one of the height and width of the linear wall structures changes continuously.

[Claim 12] The liquid crystal display apparatus of

claim 7, characterized in that the boundaries of alignment control of the one and the other substrates are aligned with each other along a line that is defined perpendicularly to the projection or slit and that alignment control condition exhibited on the boundary on the one substrate is the same as that exhibited on the boundary on the other substrate.

[Claim 13] The liquid crystal display apparatus of claim 7, characterized in that the boundaries of alignment control of the one and the other substrates are aligned with each other along a line that is defined perpendicularly to the projection or slit and that alignment control condition exhibited on the boundary on the one substrate is different from that exhibited on the boundary on the other substrate.

[Claim 14] A liquid crystal display apparatus comprising: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material, characterized in that the linear wall structures of one of the two substrates are shifted from the linear wall structures of the other substrate, as viewed perpendicularly to one of the two substrates, and each of the two substrates includes means for forming a boundary of alignment of liquid crystal molecules at fixed positions with

respect to the linear wall structures of the opposed substrate, upon the application of a voltage.

[Claim 15] The liquid crystal display apparatus of claim 14, characterized in that the means for forming a boundary of alignment of liquid crystal molecules at fixed positions are overlapped with at least a portion of the linear wall structures opposed to the means as viewed perpendicularly to one of the two substrates.

[Claim 16] The liquid crystal display apparatus of claim 14, characterized in that the liquid crystal molecules on the boundary of alignment are oriented in mutually different directions around a point.

[Claim 17] A liquid crystal display apparatus comprising: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material, characterized in that each of the linear wall structures comprises a plurality of constituent units and that the constituent units of the respective linear wall structures of the two substrates are alternately arranged on a line as viewed perpendicularly to one of the two substrates.

[Claim 18] The liquid crystal display apparatus of

claim 17, characterized in that the constituent units of the respective linear wall structures of the two substrates are arranged alternately within one pixel.

[Claim 19] The liquid crystal display apparatus of claim 17, characterized in that each of the linear wall structures has a plurality of constituent units in one pixel, and the linear wall structures are arranged substantially symmetrically in one pixel.

[Claim 20] The liquid crystal display apparatus of claim 17, characterized in that at least one of the constituent units of the linear wall structure on each said substrate includes means for forming the boundary of alignment such that liquid crystal molecules surrounding a point are directed toward that point.

[Claim 21] The liquid crystal display apparatus of claim 20, characterized in that the means for forming the boundary of alignment forms a singularity point of an alignment vector corresponding to s=1.

[Claim 22] The liquid crystal display apparatus of claim 17, characterized in that the means for forming a boundary of alignment comprise partial enlargement of the linear wall structures.

[Claim 23] A liquid crystal display apparatus comprising: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative

dielectric anisotropy and inserted between the two substrates; and linear wall structures provided in each of the two substrates for controlling alignment of the liquid crystal material, characterized in that each of the linear wall structures has a bent portion and an additional linear wall structure is arranged on the obtuse angle side of the bent portion of the linear wall structure of the substrate with the linear wall structures.

[Claim 24] A liquid crystal display apparatus comprising: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material, characterized in that each of the linear wall structures has a bent portion and that an additional linear wall structure is arranged on the acute angle side of the bent portion of the linear wall structure of the substrate opposed to the substrate with the linear wall structures.

[Claim 25] The liquid crystal display apparatus of claim 23 or 24, characterized in that if the linear wall structures are arranged neither parallel nor perpendicular to an edge of a pixel electrode, an additional linear wall structure overlapped with at least a portion of the edge of

the pixel electrode is arranged on the opposed electrode, in an area where the linear wall structure on the opposed substrate and the edge of the pixel electrode form an obtuse angle.

[Detailed Description of the Invention]

[0001]

[Field of the Invention]

The present invention relates to a liquid crystal display apparatus such as a TV set or a display. In particular, the present invention relates to a liquid crystal display apparatus including vertically aligned liquid crystal molecules.

[0002]

[Prior Art]

A liquid crystal display apparatus includes a liquid crystal material interposed between a pair of substrates. Each of the pair of substrates includes an electrode and an alignment layer. The TN liquid crystal display apparatus that has been used extensively includes horizontal alignment layers and a liquid crystal material having a positive dielectric anisotropy. When no voltage is applied, the liquid crystal molecules are aligned substantially parallel to the horizontal alignment layers. When a voltage is applied thereto, the liquid crystal molecules rise substantially perpendicularly to the horizontal alignment

layers.

[0003]

The TN liquid crystal display apparatus can have its thickness reduced as required but provides a narrow viewing angle. A method of overcoming this disadvantage and realizing a wide viewing angle is alignment division. In the alignment division technique, each pixel is divided into two regions, so that the liquid crystal molecules rise and fall toward one side in one region and rise and fall toward the opposite side in the other region. In this way, a wider viewing angle is realized by averaging the behavior of the liquid crystal molecules in one pixel.

[0004]

To control the alignment of liquid crystal molecules, the alignment layers are normally rubbed. In making the alignment division, one region of the pixel is rubbed in a first direction using a mask, and the other region of the one pixel is rubbed in a second direction opposite to the first direction using a complementary mask. As an alternative, the whole alignment layer is rubbed in the first direction, and the one or the other region of one pixel is selectively irradiated with ultraviolet rays using a mask, thereby making a pretilt difference between the one and the other regions.

[0005]

In a liquid crystal display apparatus using horizontal

alignment layers, it is necessary to rub the alignment layers and then clean the substrates provided with the alignment layers. As a result, the fabrication of the liquid crystal panel is rather complicated and the substrates may be contaminated during the rubbing treatment.

In a liquid crystal display apparatus using vertical alignment layers, on the other hand, the liquid crystal molecules are aligned substantially perpendicularly to the vertical alignment layers when no voltage is applied thereto and the liquid crystal molecules fall and become substantially parallel to the vertical alignment layers when a voltage is applied thereto. In a liquid crystal display apparatus using the vertical alignment layers, the alignment layers are also normally rubbed in order to control the alignment of the liquid crystal molecules.

[0006]

Japanese Patent Application No. 10-185836 filed by the applicant of this application proposes a liquid crystal display apparatus that can control the alignment of liquid crystal molecules without rubbing. This liquid crystal display apparatus is a liquid crystal display apparatus of a vertical alignment type, which includes vertical alignment layers and a liquid crystal material with a negative dielectric anisotropy and which has linear wall structures (such as protrusions or slits) on each of the pair of

substrates for controlling the alignment of the liquid crystal molecules.

[0007]

This liquid crystal display apparatus of the vertical alignment type has the advantages that no rubbing is required and that the alignment division is realized by providing the linearly arranged structures. Thus, this liquid crystal display apparatus of the vertical alignment type achieves a wide viewing angle and a high contrast. Since no rubbing is needed, no cleaning needs to be done after the rubbing, either. That is why the liquid crystal display apparatus can be fabricated more easily and is never contaminated during the rubbing process. As a result, the liquid crystal display apparatus realizes higher reliability.

[0008]

[Problems to be Solved by the Invention]

However, it was discovered that the liquid crystal display apparatus of the vertical alignment type, having alignment control structures (such as protrusions or a slits) on substrates for controlling alignment of the liquid crystal material, has regions where the liquid crystal molecules are not aligned with good stability, and also has some problems in brightness and response speed as will be described later.

[0009]

An object of the present invention is to provide a

liquid crystal display apparatus of a vertical alignment type that can further increase the brightness and response speed.

[0010]

[Means for Solving the Problems]

A liquid crystal display apparatus according to the present invention includes: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material. The liquid crystal display apparatus is characterized in that each of the linear wall structures comprises a plurality of constituent units.

[0011]

According to this arrangement, each linear wall structure comprises a plurality of constituent units, and the motion of different alignment regions of the liquid crystal material decreases and is quickly converged when a voltage is applied. As a result, a liquid crystal display apparatus having a high brightness and a high response speed can be provided.

According to another aspect, a liquid crystal display apparatus according to the present invention includes: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric

anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material. The liquid crystal display apparatus is characterized in that the linear wall structures of at least one of the two substrates include: means for forming a boundary of alignment of a first type in which liquid crystal molecules surrounding a point are directed to the point; and means for forming a boundary of alignment of a second type in which some of liquid crystal molecules surrounding a point are directed to the point and the other liquid crystal molecules surrounding the point are directed away from the point. The apparatus is also characterized in and that the means for forming the boundary of alignment of the first type is provided within the constituent units.

[0012]

According to still another aspect, a liquid crystal display apparatus according to the present invention includes: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material. The liquid crystal display apparatus is characterized in that the linear wall structures of one of

the two substrates are shifted from the linear wall structures of the other substrate, as viewed perpendicularly to one of the two substrates. The apparatus is also characterized in that each of the two substrates includes means for forming a boundary of alignment of liquid crystal molecules at fixed positions with respect to the linear wall structures of the opposed substrate, upon the application of a voltage.

[0013]

According to yet another aspect, a liquid crystal display apparatus according to the present invention includes: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material. The liquid crystal display apparatus is characterized in that each of the linear wall structures comprises a plurality of constituent units and that the constituent units of the respective linear wall structures of the two substrates are alternately arranged on a line as viewed perpendicularly to one of the two substrates.

[0014]

According to yet another aspect, a liquid crystal display apparatus according to the present invention

includes: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures provided in each of the two substrates for controlling alignment of the liquid crystal material. The liquid crystal display apparatus is characterized in that each of the linear wall structures has a bent portion and that an additional linear wall structure is arranged on the obtuse angle side of the bent portion of the linear wall structure of the substrate with the linear wall structures.

[0015]

According to yet another aspect, a liquid crystal display apparatus according to the present invention includes: two substrates having electrodes and vertical alignment layers; a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates; and linear wall structures, arranged in each of the two substrates, for controlling alignment of the liquid crystal material. The liquid crystal display apparatus is characterized in that each of the linear wall structures has a bent portion and that an additional linear wall structure is arranged on the acute angle side of the bent portion of the linear wall structure of the substrate opposed to the substrate with the linear wall structures.

[0016]

[Embodiments of the Invention]

Hereinafter, preferred embodiments of the present invention will be described. FIG. 1 is a schematic cross-sectional view showing a liquid crystal display apparatus according to the present invention. In FIG. 1, the liquid crystal display apparatus 10 includes a pair of transparent glass substrates 12 and 14, and a liquid crystal material 16 having a negative dielectric anisotropy and inserted between the glass substrates 12 and 14. The first glass substrate 12 has an electrode 18 and a vertical alignment layer 20, and the second glass substrate 14 has an electrode 22 and a vertical alignment layer 24. Further, a polarizer 26 is arranged on the outer surface of the first glass substrate 2, and a polarizer 28 is arranged on the outer surface of the second glass substrate 14. The first glass substrate 12 will be referred to herein as an upper substrate, while the second glass substrate 14 will be referred to herein as a lower substrate for the sake of simplicity of description.

[0017]

If the upper substrate 12 is designed as a color filter substrate, the upper substrate 12 further includes color filters and a black mask. In that case, the electrode 18 is a common electrode. If the lower substrate is designed as a TFT substrate, the lower substrate 12 includes an active

matrix driver circuit as well as TFTs. In that case, the electrode 22 comprises pixel electrodes.

[0018]

FIG. 2 is a schematic cross-sectional view illustrating a vertical alignment type liquid crystal display apparatus having linear wall structures for controlling the alignment of liquid crystal molecules. For the sake of simplicity, the electrodes 18 and 22 and the alignment layers 20 and 24 shown in FIG. 1 are omitted from FIG. 2. In FIG. 2, the upper substrate 12 has projections 30 protruding as linear wall structures toward the lower substrate 14. Likewise, the lower substrate 14 also has projections 32 protruding as linear wall structures toward the upper substrate 12. These projections 30 and 32 are elongated and extend linearly in the direction coming out of the paper of FIG. 2.

[0019]

FIG. 3 is a plan view showing how the projections 30 and 32 look when viewed from the direction pointed by the arrow III in FIG. 2. FIG. 3 also shows a portion of one pixel of the active matrix driver circuit. The active matrix driver circuit includes gate bus lines 36, drain bus lines 38, TFTs 40 and pixel electrodes 22. The projection 30 on the upper substrate 12 passes through the center of the pixel electrode 22, while the projections 32 on the lower substrate 12 extend along the gate bus lines 36. In this way, the projections 30

and 32 extend parallel to each other and are arranged alternately in a top view. The example illustrated in FIG. 3, however, is a very simple one, and the projections 30 and 32 do not have to be arranged as shown in FIG. 3.

[0020]

As shown in FIG. 2, if a liquid crystal material 16 having a negative dielectric anisotropy is interposed between the vertical alignment layers 20 and 24, the liquid crystal molecules 16A are aligned perpendicularly to the vertical alignment layers 20 and 24 when no voltage is applied thereto. In the neighborhood of the projections 30 and 32, the liquid crystal molecules 16B are aligned perpendicularly to the projections 30 and 32. The projections 30 and 32 include slopes, and therefore, the liquid crystal molecules 16B aligned perpendicularly to the projections 30 and 32 are aligned obliquely to the vertical alignment layers 20 and 24.

[0021]

When a voltage is applied to the liquid crystal material 16, the liquid crystal material 16 having a negative dielectric anisotropy is aligned perpendicularly to the electric field, and therefore, the liquid crystal molecules fall and are aligned substantially parallel to the substrate surfaces (vertical alignment layers 20 and 24). Normally, if the vertical alignment layers 20 and 24 are not rubbed, the direction in which the liquid crystal molecules fall is not

fixed, and the behavior of the liquid crystal molecules is not stabilized. If the projections 30 and 32 extending parallel to each other are provided as in this invention, however, the liquid crystal molecules 16B around these projections 30 and 32 are aligned obliquely to the vertical alignment layers 20 and 24 as if those molecules had a pretilt angle. As a result, the direction in which the liquid crystal molecules 16B fall is determined when a voltage is applied thereto.

[0022]

Take a look at the liquid crystal molecules between the projection 30 located on the left-hand side of the upper substrate 14 and the projection 32 located below and on the left-hand side of the projection 30 in FIG. 2. Then it can be seen that the liquid crystal molecules 16B between these projections 30 and 32 are aligned from the upper right toward the lower left, and therefore, rotate clockwise, fall, and are aligned parallel to the vertical alignment layers 20, 24 when a voltage is applied thereto. As a result, the liquid crystal molecules 16A between these projections 30 and 32 also rotate clockwise, fall, and are aligned parallel to the vertical alignment layers 20, 24 to repeat the behavior of the liquid crystal molecules 16B. Likewise, as to the liquid crystal molecules between the projection 30 located on the left-hand side of the upper substrate 14 and the projection

32 located below and on the right-hand side of the projection 30 shown in FIG. 2, the liquid crystal molecules 16B between the projections 30 and 32 are aligned from the upper left toward the lower right, and therefore, rotate counterclockwise, fall and are aligned parallel to the vertical alignment layers 20 and 24 when a voltage is applied thereto. As a result, the liquid crystal molecules 16A between these projections 30 and 32 also rotate counterclockwise, fall and are aligned parallel to the vertical alignment layers 20 and 24 to repeat the behavior of the liquid crystal molecules 16B.

[0023]

FIG. 4 is a view showing the liquid crystal molecules 16A that fell by being affected by the arrangement of the projections 30 and 32 of FIGS. 2 and 3 when a voltage was applied thereto. The liquid crystal molecule 16A on one side of the projection 30 of the upper substrate 12 falls while rotating clockwise with respect to the projection 30, while the liquid crystal molecule 16A on the other side of the projection 30 of the upper substrate 12 falls while rotating counterclockwise with respect to the projection 30. In FIG. 4, the liquid crystal molecules 16A are aligned perpendicularly to the paper of FIG. 2 when no voltage is applied thereto. In this way, the alignment of liquid crystal molecules can be controlled without rubbing, and a

plurality of areas in which liquid crystal molecules are aligned in multiple different directions are created within one pixel. As a result, alignment division is realized, thereby providing a liquid crystal display apparatus with a broad good viewing angle range.

[0024]

FIG. 5 is a plan view showing another example of the projections (linear wall structures) 30 and 32. The projections 30 and 32 extend parallel to each other while bending in the same pattern. In other words, the projections 30 and 32 wobble in the same zigzag pattern but extend parallel to each other. In this example, the liquid crystal molecules 16C and 16D are aligned in mutually opposite directions, and the liquid crystal molecules 16E and 16F are aligned in mutually opposite directions. The liquid crystal molecules 16C and 16D define an angle of rotation of 90 degrees with respect to the liquid crystal molecules 16E, 16F. As a result, alignment division is realized such that there are four areas in which liquid crystal molecules are aligned in mutually different directions within one pixel, thus further improving the viewing angle characteristic.

[0025]

FIG. 6 is a view schematically illustrating a liquid crystal display apparatus in which the linear wall structures are defined by the projections 30 and 32. In FIG. 6, the

electrodes 18 and 22 are shown instead of the upper and lower substrates 12 and 14, respectively. The projections 30 and 32 are provided as dielectric members on the electrodes 18 and 22, respectively. The reference numeral 42 denotes an electric field in the vicinity of the projections 30 and 32. The projections 30 and 32 are made of a dielectric material, and therefore, the electric field 42 near the projections 30 and 32 is an oblique electric field. Thus, when a voltage is applied thereto, the liquid crystal molecules fall so as to be perpendicular to the electric field 42 as pointed by the arrows. The direction in which the liquid crystal molecules have fallen due to the oblique electric field is the same as the direction in which the liquid crystal molecules have fallen due to the slopes of the projections 30 and 32.

[0026]

FIG. 7 is a schematic cross-sectional view showing a liquid crystal display apparatus in which the linear wall structures of the lower substrate 14 are the projections 32 and the linear wall structures of the upper substrate 12 are slit structures 44. The slit structures 44 include the slits of the electrode 18 of the upper substrate 12. Actually, the vertical alignment layer 20 (not shown in FIG. 7) covers the electrode 18 having the slits. Therefore, the vertical alignment layer 20 has recesses at the slits of the electrode 18. The slit structures 44 each include the slit of the

electrode 18 and the recessed portion of the vertical alignment layer 20. These slit structures 44 are elongated and extend linearly just like the projections 30 shown in FIG. 6.

[0027]

In the neighborhood of each slit structure 44, an oblique electric field 42 is generated between the electrode 18 of the upper substrate 12 and the electrode 22 of the lower substrate 14. This oblique electric field 42 is similar to the oblique electric field 42 generated near the projections 30 in FIG. 6, and the liquid crystal molecules fall due to the oblique electric field 42 when a voltage is applied thereto. In this case, the liquid crystal molecules fall just like the liquid crystal molecules falling due to the presence of the projections 30. Thus, just as the alignment of liquid crystal molecules can be controlled by the combination of the projections 30 and 32 as shown in FIG. 6, the alignment of liquid crystal molecules can be also controlled by the combination of the slit structures 44 and the projections 32.

[0028]

FIG. 8 is a schematic cross-sectional view showing a liquid crystal display apparatus in which the linear wall structures of the upper substrate 12 and the lower substrate 14 are both slit structures 44 and 46, respectively. Each

slit structure 44 is elongated and extends linearly just like the projections 30 of FIG. 6, while the slit structures 46 are elongated and extend linearly just like the projections 32 of FIG. 6. In the neighborhood of the slit structures 44 and 46, an oblique electric field 42 is generated between the electrode 18 of the upper substrate 12 and the electrode 22 of the lower substrate 14. This oblique electric field 42 is similar to the oblique electric field 42 generated near the projections 30 and 32 in FIG. 6. Accordingly, the liquid crystal molecules fall due to the oblique electric field 42 when a voltage is applied thereto. In this case, the liquid crystal molecules fall just like the liquid crystal molecules falling due to the presence of the projections 30 and 32. Thus, just as the alignment of liquid crystal molecules can be controlled by the combination of the projections 30 and 32 as shown in FIG. 6, the alignment of liquid crystal molecules can also be controlled by the combination of the slit structures 44 and 46.

[0029]

Consequently, both the projections 30 and 32 and the slit structures 44 and 46 can control the alignment of liquid crystal molecules similarly. Therefore, the projections 30 and 32 and the slit structures 44 and 46 can be collectively referred to herein by the term "linear wall structures".

FIG. 9 is a cross-sectional view showing exemplary

linear wall structures implemented as the projections 30 (32). The projections 30 may be formed in the following manner, for example. First, an electrode 22, as well as the active matrix, is formed on the lower substrate 14. Dielectric members 30A to be projections are deposited on the electrode 22. The dielectric members 30A are formed by applying a resist and patterning it. The vertical alignment layer 24 is deposited on the dielectric member 30A and the electrode 22. In this manner, the projections 30 are obtained.

[0030]

FIG. 10 is a cross-sectional view showing exemplary linear wall structures implemented as the slit structures 44 (46). The slit structures 44 may be formed in the following manner, for example. After color filters and a black matrix have been provided on the upper substrate 14, an electrode 18 is formed thereon. The electrode 18 is patterned to make slits 18A. And a vertical alignment layer 20 is deposited on the electrode 18 with the slits 18A. In this manner, the slit structures 44 are obtained.

[0031]

FIG. 11 is a view showing an alignment problem of the liquid crystal display apparatus having the linear wall structures. Although the linear wall structures are supposed to be the projections 30 and 32 in most cases, similar effects are also achieved even if the slit structures 44 and

46 are used instead of the projections 30 and 32.

FIG. 11 shows a state similar to that shown in FIG. 4. However, in FIG. 11, the projection 32 of the lower substrate 14 is located at the center. The reference numeral 48 denotes the arrangements of the polarizers 26 and 28. The polarizers 26 and 28 are arranged so as to define an angle of 45 degrees with respect to the projections 30 and 32. As described above, when a voltage is applied thereto, the liquid crystal molecules 16A are falling in opposite directions on both sides of the projection 32 of the lower substrate (or the projection 30 of the upper substrate 12). The liquid crystal molecules near the projections 32, which are located between the liquid crystal molecules falling in opposite directions, are also falling continuously with these liquid crystal molecules 16A. The liquid crystal molecules right over the projection 32 may fall either rightward or leftward in FIG. 11. However, it is not clear whether the liquid crystal molecules located right over the projections 32 fall rightward or leftward. For that reason, an alignment condition in which the liquid crystal molecules have fallen rightward and another alignment condition in which the liquid crystal molecules have fallen leftward are present on the same projection 32. And where these two alignment conditions are in contact with each other, a boundary of alignment of the liquid crystal material is formed. There are a number of

such boundaries on the single projection 32.

[0032]

Also, if the liquid crystal molecules on the projection 30 of the upper substrate 12 are aligned in the same direction as those on the projection 32 of the lower substrate 14 (as in the area C, for example) as shown in FIG. 11, the liquid crystal molecules between the projections 30 and 32 will have a splay-type alignment. On the other hand, if the liquid crystal molecules on the projection 30 of the upper substrate 12 are aligned differently from those on the projection 32 of the lower substrate 32 (as in the area A, for example), then the liquid crystal molecules between the projections 30 and 32 will have a bend-type arrangement. Specifically, two different types of alignment conditions are also present between the projections 30 and 32, and a boundary is formed between these areas in different alignment conditions.

[0033]

When observed in further detail, even the splay-type alignment changes slightly due to the misalignment of the upper and lower substrates 12 and 14. As a result, the angle between the polarizers 26 and 28 that will maximize the transmittance in one area will be different in another area. This change was actually observed by rotating the polarizers 26 and 28 in several areas. In FIG. 11, the polarizers 26

and 28 have been rotated in the area A by about -13 degrees with respect to the normal arrangement 48. The polarizers 26 and 28 have been rotated in the area B by -4 degrees with respect to the normal arrangement 48. And the polarizers 26 and 28 have been rotated in the area C by +2 degrees with respect to the normal arrangement 48.

[0034]

FIG. 12 is a graph showing the transmittances measured in the areas A, B and C of FIG. 11. The curve A shows the result of measurement in the area A of FIG. 11, the curve B shows the result of measurement in the area B of FIG. 11, and the curve C shows the result of measurement in the area C of FIG. 11.. The curve A shows that a rather high transmittance is realized when the angle formed between the polarizers 26 and 28 is significantly different from that of the normal arrangement (45 degrees with respect to the projections 30 and 32). But the curve A also shows that if the polarizers 26 and 28 have the normal arrangement 48 (45 degrees with respect to the projections 30 and 32), light is hardly transmitted. The curve B shows that a relatively high transmittance is realized when the angle formed between the polarizers 26 and 28 is slightly different from that of the normal arrangement 48 (45 degrees with respect to the projections 30, 32). The curve C shows that a certain degree of transmittance is realized when the polarizers 26 and 28

have the normal arrangement 48 (45 degrees with respect to the projections 30, 32). In this manner, there will be a number of areas with different transmittance characteristics.

[0035]

FIG. 13 is a graph showing how the transmittance changes after a voltage has been applied. If there are those areas with different alignment conditions as described with reference to FIGS. 11 and 12, a phenomenon called overshoot occurs immediately after the voltage has been applied. Specifically, the transmittance increases steeply 1000 ms after the voltage was applied, and then gradually decreases to reach an equilibrium state at a predetermined value. The overshoot is expressed by the degree to which the white brightness has increased from the transmittance in the equilibrium state. The overshoot (%) is defined as $(Y-X)/X \times 100$, where X is the initial brightness and Y is the brightness in the equilibrium state.

[0036]

As shown in FIG. 11, if there are the areas A, B and C with different transmittances, the liquid crystal molecules in these areas A, B and C continue to move in the respective areas after the voltage has been applied. In addition, the areas A, B and C themselves continue to move as being affected by the liquid crystal molecules in the adjacent areas (i.e. the boundaries between areas A, B and C continue

to move). As a result, the transmittance rises to increase the degree of overshoot. The overshoot also causes a residual image, thus debasing the display quality. Furthermore, when there are these areas A, B and C having different characteristics, the display performance also becomes inconsistent, thereby making it impossible to realize good quality constantly.

[0037]

That is why the alignment condition of liquid crystal molecules on the projections 30 and 32 is preferably controlled to prevent the liquid crystal molecules in those areas with different transmittances from moving endlessly and thereby increase the brightness and response speed.

FIG. 14 is a view showing exemplary projections (linear wall structures) 30 and 32 according to a first embodiment of the present invention. Slit structures 44 and 46 may be naturally used as alternative linear wall structures for the projections 30 and 32.

[0038]

The liquid crystal display apparatus has the projections 30 on the upper substrate 12 and the projections 32 on the lower substrate 14, as described above. Each projection 30 or 32 consists of a plurality of constituent units 30S or 32S. The constituent units 30S or 32S have a substantially uniform shape, and are distinguished from each other by a change in

the shape or cutting. In the example of FIG. 14, two adjacent constituent units 30S or 32S are connected together with a narrow portion. Also, the constituent units 30S of the projections 30 on the upper substrate 12 and the constituent units 32S of the projection 32 on the lower substrate 14 extend parallel to each other, and are arranged so as to overlap with each other.

[0039]

As described above, each projection 30 or 32 consists of a plurality of constituent units 30S or 32S, respectively, and therefore, a plurality of areas A, B and C with different transmittances as shown in FIG. 11 are less likely to be created within each constituent unit 30S or 32S. Also, the areas A, B and C do not continue to move anymore (the boundaries between the areas A, B and C do not continue to move), and the liquid crystal molecules get aligned horizontally in a shorter time. As a result, the overshoot can be reduced, thus improving both the brightness and the response speed. Even though there are areas with a significant transmittance loss, their effect can be canceled since there are a huge number of small areas with a minimum transmittance loss. For this purpose, each projection 30 or 32 preferably includes as many constituent units 30S or 32S as possible. The length of the constituent units 30S or 32S is preferably equal to or greater than the gap between the

projections 30 and 32 on the pair of substrates 12 and 14, and equal to or smaller than 200 μm.

[0040]

FIG. 15 is a view showing a modified example of the projections 30 and 32. Each of the projections 30 and 32 consists of a plurality of constituent units 30S and 32S. In this example, the projections 30 and 32 are cut off, i.e. each of the constituent units 30S and 32S is separated from adjacent ones. The other features are similar to those of the example shown in FIG. 14.

FIG. 16 is a view showing a modified example of the projections 30 and 32. Each of the projections 30 and 32 consists of a plurality of constituent units 30S and 32S. In this example, the projections 30 and 32 are arranged in a bending pattern. The other features are similar to those of FIG. 15.

[0041]

FIG. 17 is a view showing a modified example of the projections 30 and 32. The projections 30 and 32 consist of a plurality of constituent units 30S and 32S. In this example, the projections 30 and 32 are cut off, i.e. each of the constituent units 30S and 32S is separated from adjacent ones. Further, the constituent units 30S of the projections 30 on the upper substrate 12 and the constituent units 32S of the projections 32 on the lower substrate 14 extend parallel to

each other and are shifted from each other. This arrangement is advantageous because the number of domains can be further increased. Even when in contact with each other as shown in FIG. 14, the constituent units 30S and 32S making up the projections 30 and 32 on the upper and lower substrates may also be shifted as shown in FIG. 17.

[0042]

FIG. 18 is a view showing a modified example of the projections 30 and 32. The projections 30 and 32 consist of a plurality of constituent units 30S and 32S. In this example, the projections 30 and 32 are cut off, i.e. each of the constituent units 30S and 32S is separated from adjacent ones. Further, the constituent units 30S of the projections 30 on the upper substrate 12 and the constituent units 32S of the projections 32 on the lower substrate 14 have different lengths. Each constituent unit 30S of the projections 30 on the upper substrate 12 is about three times as long as each constituent unit 32S of the projections 32 on the lower substrate 14. The center of each constituent unit 30S of the projections 30 on the upper substrate 12 agrees with the center of its associated three constituent units 32S of the projections 32S on the lower substrate 14.

[0043]

FIG. 19 is a view showing a modified example of the projections 30 and 32. The projections 30 and 32 consist of

a plurality of constituent units 30S and 32S. In this example, the projections 30 and 32 are cut off, i.e. each of the constituent units 30S and 32S is separated from adjacent ones. Further, the constituent units 30S of the projections 30 on the upper substrate 12 have different lengths, and the constituent units 32S of the projections 32 on the lower substrate 14 also have different lengths. In this example, each group of constituent units 30S or 32S includes two sets of constituent units 30S or 32S of mutually different lengths, and those two sets are arranged alternately. Furthermore, each set of constituent units 30S of the projections 30 on the upper substrate 12 and its associated set of constituent units 32S of the projections 32 on the lower substrate 14 are shifted from each other. Alternatively, the constituent units 30S, 32S shown in FIGS. 18 and 19 may be aligned with each other or connected together as in the examples described above.

[0044]

FIG. 20 is a view showing a modified example of the projections 30 and 32. Each of the projections 30 and 32 consists of a plurality of constituent units 30S, 32S, respectively. In this example, the constituent units 30S of each projection 30 are arranged alternately with the constituent units 32S of its associated projection 32, and the constituent units 32S of each projection 32 are arranged

alternately with the constituent units 30S of its associated projection 30. For example, the constituent units 30S of each projection 30 on the upper substrate are arranged at every other position of the projection 30 shown in FIG. 2, and the constituent units 32S of each projection 32 on the lower substrate are arranged at every other position right under the projection 30 shown in FIG. 2 so as to fill the voids where no constituent units 30S of the projection 30 on the upper substrate are present. It seems that a train of constituent units is formed by the constituent units 30S, 32S of the projections 30 and 32 on the upper and lower substrates.

[0045]

In the examples described above, the constituent units 30S and 32S of the projections 30 and 32 are illustrated in an elliptical shape. The present invention, however, is not limited to those specific examples but the units may also have rectangular, diamond or any other polygonal shape. Also, in order to average the lengths of the constituent units 30S and 32S of the projections 30 and 32, the length is preferably equal to or smaller than the combined length of a set of R, G and B pixels, i.e. 200 μm or less. Furthermore, since the gap between the projections when the pair of substrates are stacked one upon the other becomes the minimum distance for controlling the alignment of liquid crystal

molecules, the lengths of the constituent units 30S and 32S of the projections 30 and 32 are preferably equal to or greater than this projection gap.

Although various examples using the projections 30 and 32 have been described, the same statement also applies to a situation where slit structures 44 and 46 including electrode slits are used. In other words, each slit may consist of a plurality of constituent units. In that case, the arrangements descried above may also be used as they are. The lengths of the constituent units are also limited similarly.

[0046]

FIG. 21 is a view showing a modified example of the linear wall structures. FIG. 21 shows portions of three pixel electrodes 22R, 22G and 22B, and the linear wall structures have the bending pattern shown in FIG. 5. The linear wall structures on the upper substrate 12 include projections 30, while the linear wall structures on the lower substrate 14 include slit structures 46. That is to say, the linear wall structures shown in FIG. 21 are obtaining by arranging the projections and the slit structures shown in FIG. 7 upside down.

[0047]

FIG. 22 is a view showing the pixel electrode 22R and the slit structures 46 shown in FIG. 21. The pixel electrode

22R has a plurality of slits 22S and a plurality of inter-slit portions 22T made of the same material (ITO) as the pixel electrode 22R. The slits 22S may be made when the pixel electrode 22R is patterned. If the vertical alignment layer 24 is applied on the pixel electrode 22R, the series of slits 22S of the pixel electrode 22R will form the slit structure 46, and the slits 22S will be the constituent units 46S of the slit structure 46. The portions 22T of that material separate adjacent constituent units 46S from each other.

[0048]

In this preferred embodiment, the slits 22S (the constituent units 46S of the slit structure 46) preferably have a width of 5 μm and lengths of 12 μm, 26 μm and 33 μm. The length of the slits 22S (the constituent units 46S of the slit structure 46) is preferably 10 μm or more. The length of the material portion 22T was 4 μm. The length of the material portion 22T is preferably equal to or smaller than the width of the projection 30. Likewise, the constituent units 30S of the projections 30 have a width of 5 μm and lengths of 12 μm, 26 μm and 33 μm. The length of the gap between the constituent units 30S of the projection 30 was 4 μm.

[0049]

FIGS. 23(A) to 23(E) are views showing how to form the

linear wall structures consisting of the projections 30. As shown in FIG. 23(A), a substrate 12 was prepared and color filters, a black matrix and an electrode 18 were provided thereon. As shown in FIG. 23(B), the substrate 12 having the electrode 18 (not shown) was spin-coated with LC 200 (produced by Shipley), which is a positive resist 50, at 1500 rpm for 30 seconds. A positive resist was used in this example but does not have to be used. A negative resist or a photosensitive resin other than a resist may also be used. As shown in FIG. 23(C), the resist 50 applied by the spin coating was prebaked at 90 ℃ for 20 minutes, and then subjected to a contact exposure process through a photomask 52 (exposure time: 5 seconds). As shown in FIG. 23(D), after having been developed with a developer produced by Shipley for one minute, the resist was post-baked at 120 ℃ for 60 minutes and then at 200 ℃ for 40 minutes, thereby forming projections 30. This projection 30 had a width of 5 μm and a height of 1.5 μm, and the constituent units 30S of the projections 30 had the lengths mentioned above. As shown in FIG. 23(E), a vertical alignment layer JALS 684 (produced by JSR) was applied by spin coating at 2000 rpm for 30 seconds, and then baked at 180 ℃ for 60 minutes to obtain the vertical alignment layer 20.

[0050]

A seal (XN-21F produced by Mitsui Toatsu Chemical Inc.)

was applied to one of this substrate 12 and the TFT substrate 14, and 4.5 μm spacers (SP-20045, produced by Sekisui Fine Chemical Co., Ltd.) were dispersed on the other substrate. Then, these two substrates were stacked one upon the other. Finally, the assembly was baked at 135 ℃ for 60 minutes to make an empty panel. Neither rubbing nor cleaning was conducted. Next, a liquid crystal material MJ961213 (produced by Merck & Co., Inc.) with a negative dielectric anisotropy was injected into the empty panel in a vacuum. The injection port was finally sealed with a sealing material (30Y@228, produced by Three Bond Co., Ltd.), thereby completing a liquid crystal panel.

[0051]

The transmittance of the liquid crystal panel fabricated in this way was 25.7% when a voltage of 5 V was applied thereto. Also, when the response speed was measured with voltages of 0 V to 5 V applied thereto, the overshoot was 1.6%.

The liquid crystal display apparatus having the linear wall structures shown in FIG. 15 exhibited a transmittance of 26.3% when a voltage of 5 V was applied thereto. When the response speed was measured with voltages of 0 V to 5 V applied, the overshoot was 1.1%. The projections had a width of 10 μm and a height is 1.5 μm, the constituent units of the projections had a length of 30 μm, the gap between the

projection constituent units was 10 μm, and the gap between the projections was 20 μm when the upper and lower substrates were stacked one upon the other.

[0052]

On the other hand, a liquid crystal display apparatus with the linear wall structures shown in FIG. 17 exhibited a transmittance of 26.6% when a voltage of 5 V was applied thereto. When the response speed was measured with voltages of 0 V to 5 V applied, the overshoot was 0.9%. A liquid crystal display apparatus with the linear wall structures shown in FIG. 18 exhibited a transmittance of 26.1% when a voltage of 5 V was applied thereto. When the response speed was measured with voltages of 0 V to 5 V applied, the overshoot was 1.6%. In this case, the projections had a width of 10 μm and a height of 1.5 μm, the projection constituent units on one substrate had a length of 30 μm, the projection constituent unit on the other substrate had a length of 70 μm, the gap between the projection constituent units was 10 μm and the gap between the projections was 20 μm when the upper and lower substrates were stacked one upon the other. Also, a panel was fabricated by bonding the pair of substrates together such that each long projection constituent unit was aligned with two associated short projection constituent units.

[0053]

A liquid crystal display apparatus with the linear wall structures shown in FIG. 20 exhibited a transmittance of 26.0% when a voltage of 5 V was applied thereto. When the response speed was measured with voltages of 0 V to 5 V applied, the overshoot was 1.6%. In this case, the projections had a width of 10 μm and a height of 1.5 μm, the projection constituent units had a length of 30 μm, the gap between the projection constituent units on one substrate was 50 μm, the gap between the projections constituent units on the other substrate was 10 μm, and the gap between the projections was 20 μm when the upper and lower substrates were stacked one upon the other. Also, the projections were arranged such that the gaps between the projection constituent units on one substrate were aligned with the projection constituent units on the other substrate.

[0054]

The following measurements were carried out as Comparative Example No. 1. A liquid crystal panel was fabricated so as to include projections having no constituent units. The projections had a width of 10 μm and a height of 1.5 μm, and the gap between the projections was 20 μm when the upper and lower substrates were stacked one upon the other. The transmittance was 22.8% when a voltage of 5 V was applied thereto. Also, when the response speed was measured with voltages of 0 V to 5 V applied, the overshoot was 7.5%.

[0055]

The following measurements were carried out as Comparative Example No. 2. A liquid crystal panel was fabricated so as to have projections similar to those shown in FIG. 15 but having longer constituent units. The projections had a width of 10 μm and a height of 1.5 μm, the projection constituent units had a length of 300 μm, the gap between the projection constituent units was 10 μm, and the gap between the projections was 20 μm when the upper and lower substrates were stacked one upon the other. The transmittance was 23.5% when a voltage of 5 V was applied thereto. Also, when the response speed was measured with voltages of 0 V to 5 V applied, the overshoot was 6.3%.

[0056]

The following measurements were carried out as Comparative Example No. 3. A liquid crystal panel was fabricated so as to have projections similar to those shown in FIG. 15 but having longer constituent units. The projections had a width of 10 μm and a height of 1.5 μm, the projection constituent units had a length of 10 μm, the gap between the projection constituent units was 10 μm, and the gap between the projections was 20 μm when the upper and lower substrates were stacked one upon the other. The transmittance was 24.1% when a voltage of 5 V was applied thereto. Also, when the response speed was measured with

voltages of 0 V to 5 V applied, the overshoot was 5.9%.

[0057]

FIG. 24 is a view showing the alignment of liquid crystal molecules in a liquid crystal display apparatus having similar linear wall structures to those shown in FIG. 11. FIG. 25 shows the display characteristic of the arrangement shown in FIG. 24. In FIG. 25, the reference numeral 54 denotes areas that look dark.

In FIG. 24, the liquid crystal molecules located between the projection 30 on the upper substrate 12 and the projection 32 on the lower substrate 14 are aligned substantially perpendicularly to the projections 30 and 32. Meanwhile, the liquid crystal molecules on the projections 30 and 32 are aligned substantially parallel to the projections 30 and 32.

[0058]

It was discovered that the boundaries and the number of divisions of the areas having different alignment conditions on the projections 30 and 32 continued to change for several to even several tens of seconds after the voltage was applied. It was also discovered that the overshoot was caused mainly because this phenomenon was observed as a variation in the transmittance of a liquid crystal panel.

This phenomenon would be brought about in the following manner. The liquid crystal molecules on the projections 30

and 32 can be aligned either rightward or leftward if the projections 30 and 32 extend horizontally as shown in FIG. 24, for example. If there were no means for controlling the directions, however, the liquid crystal molecules would fall randomly in one of two directions immediately after the voltage has been applied. After that, the areas in different alignment conditions on the projections 30 and 32 will affect each other. However, since the alignment directions of the liquid crystal molecules are not regulated in these areas, the liquid crystal molecules would easily change their states when affected by the molecules surrounding them. In this way, the liquid crystal molecules within those areas in different alignment conditions on the projections 30 and 32 would continue to move for a long time.

[0059]

However, if the projections or slit structures consist of a plurality of constituent units as described above, the alignment directions can be regulated with respect to the boundary between the constituent units divided.

FIG. 26 is a view showing how liquid crystal molecules are aligned in a liquid crystal display apparatus having linear wall structures including a plurality of constituent units. FIG. 27 shows the display characteristic of the arrangement shown in FIG. 26. In FIG. 27, the reference numeral 54 denotes areas that look dark. FIGS. 26 and 27

show the features of the liquid crystal molecules in the liquid crystal display apparatus shown in FIG. 15, for example.

[0060]

Those areas in different alignment conditions on the projections 30 and 32 are separated from each other by the cut portions 30T and 32T. The observation showed that no changes with time were sensed in the liquid crystal molecules at the cut portions 30T and 32T. It was newly discovered, however, that there were also a plurality of areas in which liquid crystal molecules were aligned in different conditions between each cut portion 30T or 32T and adjacent cut portions (even in the constituent units 3-S and 32S of the projections). It was discovered that the boundaries between these areas also exhibited some variations (albeit lighter than conventional ones) with time and that there was still some room of improvement in terms of the overshoot.

[0061]

FIG. 28 is a view showing the alignment of liquid crystal molecules in a liquid crystal display apparatus having linear wall structures according to a second preferred embodiment of the present invention. FIG. 29 shows the display characteristic of the arrangement shown in FIG. 28. FIG. 30 shows the features of the boundaries of alignment of first and second types illustrated in FIG. 28 on a larger

scale.

In FIGS. 28 and 30, while looking for a means for controlling the alignment of liquid crystal molecules on the projections 30 and 32, the present inventors sensed that there are two types of boundaries between those areas in which the liquid crystal molecules have different alignment conditions. In the first type (I), the liquid crystal molecules surrounding a point are all directed toward that point. In the second type (II) on the other hand, some of the liquid crystal molecules surrounding a point are directed toward that point but the other molecules are directed away from that point. In FIG. 28, the liquid crystal molecules are shown to have a head and a leg. In the first type (I), the heads or the legs of all liquid crystal molecules are directed toward the center. In the second type (II), on the other hand, some liquid crystal molecules have their head directed toward the center but the other liquid crystal molecules have their leg directed toward the center.

[0062]

In FIG. 28, the projections 30 and 32 as the linear wall structures of the respective substrates include means 56 for forming boundaries of alignment of the first type (I) in which the liquid crystal molecules surrounding a point are directed toward that point, and means 58 for forming the boundaries of alignment of the second type (II) in which some

of the liquid crystal molecules surrounding a point are directed toward that point and the other liquid crystal molecules are directed away from that point. The means 56 for forming the boundaries of alignment of the first type (I) are arranged within the constituent units 30S and 32S of the projections 30 and 32, while the means 58 for forming the boundaries of alignment of the second type (II) are arranged in the boundaries between the constituent units 30S, 32S of the projection 30, 32 (i.e. in the separating portions 30T and 32T for separating the constituent units 30S and 32S from each other).

[0063]

As can be seen from the foregoing description and FIG. 2, the projections 30 and 32 can control the alignment of liquid crystal molecules using the main slopes thereof. Likewise, the separating portions 30T and 32T defining the boundaries between the constituent units 30S and 32S of the projections 30 and 32 also have slopes, with which the alignment of liquid crystal molecules can be controlled. The slopes of the separating portions 30T and 32T extend substantially along the length of projections 30 and 32. The main slopes of the projections 30 and 32 have the function of aligning the liquid crystal molecules perpendicularly to the length of the projections 30 and 32. On the other hand, the slopes of the separating portions 30T and 32T align the liquid crystal

molecules substantially parallel to the length direction of the projections 30 and 32. On the whole, though, the liquid crystal molecules tend to be aligned perpendicularly to the length of the projections 30 and 32, and the separating portions 30T and 32T also have a similar function. Thus, the separating portions 30T and 32T provide the means 58 for forming the boundary of the second type (II).

[0064]

FIGS. 31 and 32 show specific examples of the means 56 for forming the boundaries of alignment of the first type (I). FIG. 32 is a cross-sectional view in which a cross section of the projection 30 on the upper substrate 12 and a cross section of the projection 32 on the lower substrate 14 are combined with each other. This means 56 includes dotted protrusions provided on the projection 30 and 32, respectively. The means 56 aids the alignment of liquid crystal moles in terms of shape or electric field and thus can align the liquid crystal molecules as described above. Accordingly, the alignment areas of liquid crystal molecules on the projections 30 and 32 can be divided at these points. The liquid crystal molecules on the boundary of the first type (I) are aligned differently from those on the boundary of the second type (II), and therefore, the projections naturally have different effects on them.

[0065]

The means 56 for forming the boundaries of alignment of the first type (I) can make the liquid crystal molecules fall toward the raised portion of the projections on the upper substrate 12. It is not until the recessed portions and the raised portion of the projection are arranged alternately in this way that the alignment directions of all domains can be defined on the projections. Thus, the variation of the liquid crystal domains with time can be minimized after the voltage has been applied, and the overshoot can be substantially eliminated. In FIG. 29, every boundary position can be controlled and the dark portions on the screen can be reduced.

[0066]

In order to provide the means 56 protruding on the projections 30 and 32, small structures were formed before the projections 30 and 32 were made. Those structures may be formed after the projections 30 and 32 have been made. The small structures were 10 μm square and had a height of 1 μm. In this example, the small structures are made of the same material as the projections. In providing the small structures on a TFT substrate, there is a method in which a metalized interconnection layer or an insulating layer is deposited where those structures should be formed. When provided on a CF substrate, on the other hand, the desired structures can be obtained without increasing the number of

process steps just by depositing a color layer or a BM in the areas in question.

[0067]

A photosensitive acrylic material PC-335 (produced by JSR) was used as the material of the projections. The projections had a width of 10 μm, a projection gap (i.e., the distance from the end of the projection on one substrate to the end of the projection on the other substrate after the substrates were bonded together) of 30 μm, and a projection height of 1.5 μm (more exactly 2.5 μm in the raised portions of the projection, of which the height was set 1 μm higher than the other portions in advance). The separating portions 30S and 32S of the projections 30 and 32 were 10 μm square, and the distance from the center of the separating portions 30S and 32S to the center of the raised portion 56 of the projections 30 and 32 was 60 μm (i.e., a projection with a height of 1.5 μm was present continuously for a length of 50 μm).

[0068]

The vertical alignment layer was made of JALS-204 (produced by JSR Corp). Micropearl spacers (produced by Sekisui Fine Chemical Co., Ltd.) with a diameter of 3.5 μm were dispersed in the liquid crystal material, which was MJ95785 (produced by Merck & Co., Inc.) in this example.

FIGS. 33 and 34 are respectively a plan view and a

cross-sectional view, respectively, showing a modified example of the linear wall structures. This example is similar to the previous one except the following points. Specifically, the upper and lower substrates 12 and 14 had projections 30 and 32, respectively, and the raised portions and the recessed portions were alternately formed in the projections 30 and 32 as the means 56 for forming the boundaries of alignment of the first type (I) and the means 58 for forming the boundaries of alignment of the second type (II). The recessed portions 58 of the projections 30 and 32 are the separating portions 30T and 32T for separating the constituent units 30S and 32S from each other. The recessed portions 58 had a projection height of 1 μm. As a method of reducing the height of the projections, the projections 30 and 32 formed in this embodiment were selectively ashed by being exposed to oxygen plasma. Also, if the projections are formed on a TFT substrate, contact holes may be cut through the areas in question. For a CF substrate on the other hand, the color layer and the overcoat layer may be removed from the areas in question. In either case, the desired structure can be obtained without increasing the number of process steps.

[0069]

FIG. 35 is a plan view showing a modified example of the linear wall structures. The upper and lower substrates 12

and 14 had projections 30 and 32. The projections 30 and 32 had alternately wide portions and narrow portions as the means 56 for forming the boundaries of alignment of the first type (I) and the means 58 for forming the boundaries of alignment of the second type (II). The width of the wide portion 56 was 15 μm, and the width of the narrow portion 58 was 5 μm (the normal width was 10 μm).

[0070]

FIG. 36 is a plan view showing a modified example of the linear wall structures. The upper and lower substrates 12 and 14 had projections 30 and 32. A wide portion and a narrow portion were alternately arranged in the projections 30 and 32 as the means 56 for forming the boundaries of alignment of the first type (I) and the means 58 for forming the boundaries of alignment of the second type (II) with the widths of the projections 30 and 32 changed continuously.

FIG. 37 is a plan view showing a modified example of the linear wall structures. The upper substrate 12 was a CF substrate, and the lower substrate 14 was a TFT substrate. The panel size was 15-inch type, and the numbers of pixels were 1024 $\times$ 768 (XGA). FIG. 37 shows one pixel unit of the panel. The center portions 32P of the projections 32 on the TFT substrate 14 were lowered, while the center portions 30P of the projections 30 on the CF substrate 12 were raised. Taking the effect of the edge of the pixel electrodes 22 into

account, the desired alignment state was realized.

[0071]

When the present invention is applied to a liquid crystal panel using a TFT substrate, it is necessary to consider how the edge of the pixel electrodes 22 on the TFT substrate affects the direction of the electric field.

FIG. 38 is a cross-sectional view showing an edge of a pixel electrode 22 of the liquid crystal display apparatus and its surrounding portions. FIG. 39 shows the alignment of liquid crystal molecules at the edge of the pixel electrode 22 shown in FIG. 38. FIG. 39(A) shows a portion of the projection 30 on the upper substrate 12, and FIG. 39(B) shows a portion of the projection 32 on the lower substrate 14. As shown in FIGS. 38 and 39, an oblique electric field 60 is present at the edge of the pixel electrode 22. This oblique electric field 60 plays the role of directing the liquid crystal molecules toward the center of the pixel. This means that the edge of the pixel electrode 22 functions with respect to the projection 32 on the TFT substrate as if it was the means 56 for forming the boundary of alignment of the first type (I), and functions with respect to the projection 30 on the CF substrate as if it was the means 58 for forming the boundaries of the second type (II).

[0072]

In other words, the boundary nearest to the edge of the

pixel electrode on the projection 32 of the TFT substrate is always in the condition of alignment of the first type (I) and the boundary nearest to the edge of the pixel electrode on the projection 30 of the CF substrate is always in the condition of the second type (II). As a result, the configuration shown in FIG. 37 realizes the alignment control of all domains on the projections of a TFT liquid crystal panel by determining the directions of alignment on the projections 30 and 32 in accordance with the direction of regulation by the edge of the pixel electrode.

[0073]

FIG. 40 is a plan view showing a modified example of the linearly arranged structures. For the TFT substrate, the projection height is reduced as the alignment control means 58 on the projection 32 nearest to the edge of the pixel electrode, while the projection height is increased inside that area as the alignment forming means 56. For the CF substrate, on the other hand, the projection height is increased as the alignment control means 56 on the portion of the projection 30 nearest to the pixel edge, while the projection height is reduced inside that area as the alignment forming means 58.

[0074]

In the embodiments described above, the projections of the same type are provided for both of the upper and lower

substrates, but it is not always necessary to do so. For example, similar effects are achievable even if the upper substrate had high projections and low projections, while the lower substrate had wide projection and narrow projections. Also, only those two types of shapes need not be arranged alternately on the same projection.

For example, the high and low projections do not always have to be arranged alternately and repeatedly. Alternatively, a high projection, a low projection, a wide projection, a narrow projection, a high projection and a low projection may be arranged in this order, for example. In any case, it is only necessary that multiple shapes that form the boundaries of the first and second types (I) and (II) are arranged alternately. Such shape variation options are shown in the following Table 1 for the projections and the slits.

[0075]

Table 1

-- Means 56 for forming boundaries of first type (I) --

Increase projection height

Increase projection width

Increase slit height (protrude)

Increase slit width

Edge of pixel electrode

-- Means 58 for forming boundaries of second type (II) --

Cut projection

Reduce projection height

Reduce projection width

Cut slit

Reduce slit height (cut a hole)

Reduce slit width

Edge of pixel electrode

FIG. 41 is a view showing how liquid crystal molecules are aligned on the linear wall structures shown in FIG. 35. In this case, the liquid crystal molecules have the bend alignment within the display domain.

[0076]

FIG. 42 is a view showing a modified example of the linear wall structures shown in FIG. 41. In this case, the liquid crystal molecules have the splay alignment within the display domain. By changing from the configuration shown in FIG. 41 into that shown in FIG. 42, the bend alignment can be changed into the splay alignment.

FIG. 43 is a plan view showing linear wall structures according to a third embodiment of the present invention. FIG. 44 is a cross-sectional view of the liquid crystal display apparatus showing a cross section of the linear wall structures shown in FIG. 43. The basic configuration of this liquid crystal display apparatus 10 is similar to that of the liquid crystal display apparatus 10 of the embodiment shown

in FIGS. 1 to 5. Specifically, the liquid crystal display apparatus 10 includes projections 30 and 32 as linear wall structures for controlling the alignment of the liquid crystal material. The projections 30 and 32 are arranged so as to be parallel to each other and shifted from each other when viewed perpendicularly to the substrates. FIG. 44 is a cross-sectional view of the projection 32 on the lower substrate 14 and does not show the projection 30 on the upper substrate 12.

[0077]

In this embodiment, the upper substrate 12 and the lower substrate 14 respectively include means 62 and 64 for forming the boundary of alignment of liquid crystal molecules at fixed positions on the opposed substrate when a voltage is applied thereto. In FIG. 44, the upper substrate 12 includes means 62 having a dotted projection 62 in the same cross-section as the projection 32 on the lower substrate 14. Likewise, as shown in FIG. 43, the lower substrate 14 includes means 64 having a dotted projection 64 in the same cross-section as the projection 30 on the upper substrate 12.

[0078]

FIG. 45 is a view showing the alignment of liquid crystal molecules near the linearly arranged structures shown in FIG. 44. FIG. 46 is a view showing the alignment of liquid crystal molecules near the linear wall structures of

the first embodiment.

In the first embodiment, the projections 30 and 32 consist of a plurality of constituent units 30S and 32S. The means 62 and 64 for forming the boundary of alignment of liquid crystal molecules at predetermined positions according to this embodiment have the same function as the projections 30 and 32 consisting of a plurality of constituent units 30S and 32S in the first embodiment. Thus, as can be seen when FIGS. 45 and 46 are compared, the positions where the means 62 and 64 are provided along the projections 30 and 32 are the same as the cut portions or the boundaries of a plurality of constituent units 30S and 32S in the first embodiment.

[0079]

As shown in FIGS. 44 and 45, the means 62 is provided to make the liquid crystal molecules on the projection 32 fall toward the means 62. In the same way, the means 64 is provided to make the liquid crystal molecules on the projection 30 fall toward the means 64. Thus, it is seen that the means 62 and 64 have the same significance as the projections 30 and 32 consisting of a plurality of constituent units 30S and 32S such that the liquid crystal molecules would fall toward the cut portions or the boundaries 32T.

[0080]

In the arrangement shown in FIG. 46, the liquid crystal

molecules beside the projection 32 are preferably aligned perpendicularly to the projection 32. However, not all of the liquid crystal molecules beside the cut portions or the boundaries 32T are completely perpendicular to the projection 32 because the projection 32 discontinues there. In the arrangement shown in FIGS. 44 and 45, the projection 32 is not discontinuous, and therefore, the liquid crystal molecules beside the projection 32 all face the projection 32 perpendicularly. Thus, the alignment of liquid crystal molecules can be controlled in both the display area and the area on the projection without decreasing the brightness.

[0081]

The dotted projections 62 and 64 were made of a photosensitive acrylic material PC-335 (produced by JSR Corp). The dotted projections 62 and 64 had a width of 5 μm and a height of 1.5 μm. The linear projections 30 and 32 had a width of 10 μm and a height of 1.5 μm.

FIG. 47 is a view showing a modified example of the linear wall structures and the means for controlling the boundary alignment. In this embodiment, the means 62 for forming the boundary of alignment of liquid crystal molecules at a predetermined position is a dotted slit structure 62. The means 62 is obtained by cutting a slit through the electrode 18 and depositing a vertical alignment layer 20 on the electrode 18.

[0082]

FIG. 48 is a view showing a modified example of the linear wall structures and the means for controlling the alignment in the boundaries. In this embodiment, the means 62 for forming the boundary of alignment of liquid crystal molecules at a predetermined position is a dotted projection 62. The dotted projection 62 is made by cutting a slit or a hole through the electrode 18, forming a projection 66 on the substrate within this slit or hole, and then depositing a vertical alignment layer 20 on the electrode 18. The dotted projection 62a had a width of 3 μm, a length of 8 μm, and a height of 1.5 μm. The projection 66 was made of an acrylic resin. As alternative projection forming means, the material of bus lines or insulating layer may be selectively used for a TFT substrate. As for a CR substrate on the other hand, the material of a color filter layer, a black mask layer or an overcoat layer may be selectively used.

[0083]

Also, instead of providing the projection 66, a slit or a hole may be cut as a recess on the substrate such that the means 62 for forming the boundary of alignment of liquid crystal molecules at a predetermined position is a slit structure. In that case, as for a TFT substrate, a contact hole can be selectively opened as a recess. As to a CR substrate on the other hand, a recess may be formed

selectively on a color filter layer, a black mask layer or an overcoat layer.

[0084]

FIG. 49 is a view showing a modified example of the linear wall structures and the means for controlling the boundary of alignment. According to this embodiment, the means 62 for forming the boundary of alignment of liquid crystal molecules at a predetermined position is a dotted projection 62. This means 62 is obtained by making a projection 68 on the substrate 12, forming an electrode 18 thereon, and then depositing a vertical alignment layer 20 thereon. The means 62 may also be a slit structure by cutting a recess on the substrate 12.

[0085]

FIG. 50 is a view showing a modified example of the linear wall structures and the means for controlling the boundary of alignment. In FIGS. 43 to 49, the linear wall structures consist of the projections 30 and 32. As an alternative, the linear wall structures may also be the slit structures 44 and 46 (FIGS. 7 and 8). In this embodiment, the linear wall structures are the slit structures 46, and the means 62 for forming the boundary of alignment of liquid crystal molecules at a predetermined position is the dotted projection 62a. This means 62 is obtained by making a projection 68 on the substrate 12, forming an electrode 18

thereon and then depositing a vertical alignment layer 20 thereon.

[0086]

FIG. 51 is a view showing a modified example of the linear wall structures and the means for controlling the boundary of alignment. In this example, bending projections 30 and 32 are provided as the linear wall structures. As described above, it is necessary to consider the effect of the oblique electric field applied from the edge of the pixel electrode 22 on the TFT substrate onto the counter electrode 18. In this case, among the wedge-shaped disclinations on the projection 32 on the TFT substrate, the disclination closest to the edge of the pixel electrode has an intensity s =-1, which corresponds to the boundary of the first type (I) shown in FIG. 28. Among the wedge-type disclinations on the projection on the CF substrate, the disclination closet to the edge of the pixel electrode has an intensity s=+1, which corresponds to the boundary of the second type (II) shown in FIG. 28. When the present invention is actually applied to a liquid crystal panel, the direction of alignment on the projections 30 and 32 is preferably determined in accordance with how the disclination is formed by the edge of the pixel electrode 22, thereby controlling all domains in the pixel with good stability.

[0087]

In this embodiment, a portion of the electrode, located in an opposing portion of the projection 30 on the CF substrate, is selectively raised to function as the means 64 for forming the boundary of alignment of liquid crystal molecules at a predetermined position. Also, an opposing portion of the projection 32 on the TFT substrate is selectively raised, thereby providing the means 62 for forming the boundary of alignment of liquid crystal molecules at a predetermined position. Furthermore, if a plurality of wedge-shaped disclinations are arranged on one projection in a pixel, an alignment control means is provided to arrange disclinations with s = -1 and those with s = +1 alternately. According to this embodiment, the protruding portions 62 (68) of the electrode 22 and the projections 62 (69) protruding over the electrode 22 are arranged alternately as shown in FIG. 52.

[0088]

FIGS. 54 and 55 are views showing a modified example of the linear wall structures and the means for controlling the boundary of alignment. In this embodiment, the means 62 for forming the boundary of alignment of liquid crystal molecules at a predetermined position is provided as an elongated slit 62 (71) extending along the projection 70 on the upper substrate 12 so as to face the projection 32 on the lower substrate. The projection 70 is arranged on the electrode 18

and narrower than the projection 32.

[0089]

FIGS. 56 and 57 are views showing a modified example of the linear wall structures and the means for controlling the boundary of alignment. In this embodiment, the means 62 for forming the boundary of alignment of liquid crystal molecules at a predetermined position is provided as an elongated slit 62 (71) extending along the projection 70 on the upper substrate 12 so as to face the projection 32 on the lower substrate and a slit 62 (72) of the electrode 18. The projection 70 is arranged on the electrode 18 and narrower than the projection 32.

[0090]

FIG. 58 is a plan view showing linear wall structures according to a fourth embodiment of the present invention. FIG. 59 is a cross-sectional view of the liquid crystal display apparatus as viewed on the plane 59-59 in FIG. 58. The basic configuration of this liquid crystal display apparatus 10 is similar to that of the liquid crystal display apparatus 10 according to the embodiment shown in FIG. 1 to 5. In this embodiment, the projections (linear wall structures) 30 and 32 consist of a plurality of constituent units 30a and 32a, respectively. As viewed perpendicularly to one of the two substrates, the constituent units of the linear wall structure on the one substrate and those of the linear wall

structure on the other substrate are arranged alternately along a line.

[0091]

Looking at the constituent units of the projections on the upper line (line 59-59) in FIG. 58, for example, it can be seen that the constituent units 30a of the projection 30 on the upper substrate 12 and the constituent units 32a of the projection 32 on the lower substrate 14 are alternately arranged on this line. FIG. 59 shows these constituent units 30a and 32a. As shown in FIG. 59, the liquid crystal molecules on this line fall continuously toward a direction parallel to that line. Thus, as already described with reference to FIG. 11, it is possible to overcome the problem that the liquid crystal molecules on the projection fall in random directions.

[0092]

Looking at the left half of FIG. 58, the relative positions of the constituent units 32a of the projection 32 on the lower substrate 14 on the upper line, the constituent units 30a of the projection 30 on the upper substrate 12 on the intermediate line, and the constituent units 32a of the projection 32 on the lower substrate 14 on the lower line, are the same as those shown in FIGS. 3 and 4. These relative positions are similar to a situation where these projections face each other on an oblique plane with respect to the

substrate surface as shown in FIG. 2. The same statement also applies to FIG. 58. Thus, the liquid crystal display apparatus of this example works in basically the same way as the counterpart of the first embodiment. According to this arrangement, in particular, the response speed can be increased significantly at a gray-scale tone. The configuration shown in FIG. 58 is similar to that shown in FIG. 20.

[0093]

FIGS. 60 and 61 are views showing a modified example of the linear wall structures. In this example, the projection 30 is used as a linear wall structure for the upper substrate 12, while the slit structure 46 is used as a linear wall structure for the lower substrate 14. The slit structure 46 may be divided into the constituent units 46a as shown in FIG. 61. In this case, the electrical connection between the individual pixel electrodes separated by the slits is realized at a greater width, thereby allowing a broader design margin. Another advantage is that there is no concern about disconnection or increase in the resistance of the connecting portion between the slits of the pixel electrode 22.

[0094]

In this example, each linear wall structure has a plurality of constituent units in one pixel and the linear

wall structure is arranged substantially symmetrically within the same pixel. A similar feature is also achieved when this configuration is applied to the linear wall structures that are bending as shown in FIG. 21.

FIG. 62 is a view showing a modified example of the linear wall structure. In this example, the constituent units 30a and 32a of the projections 30, 32 are arranged alternately as in FIG. 58, and at least one of the constituent units 30a and 32a of the projections 30 and 32 on the respective substrates includes means 74 for forming the boundary of alignment such that liquid crystal molecules surrounding a point are directed toward that point. The means 74 for forming the boundary of alignment may be similar to the means 56 for forming the boundary of alignment of the first type (I) shown in FIG. 28. The alignment of the first type (I) forms a singularity point of the alignment vector corresponding to s=1. In this case, the alignment vectors of the minor domains on the projection can be controlled. As a result, the display domains can be controlled with good stability and the response speed can be increased at a gray-scale tone.

[0095]

This means 74 may be similar to the counterpart of the second embodiment described above.

FIG. 63 shows a specific example of the means 74 for

forming the boundary of alignment. In FIG. 63, this means 74 broadens the widths of the constituent units 30a and 32a of the projections 30 and 32.

Alternatively, the means 74 may also be provided by increasing the height of the constituent units 30a and 32a of the projections 30 and 32 as shown in FIG. 64.

[0096]

At a point where the width or height of the constituent units 30a and 32a of the projections is partially increased, the liquid crystal directors spread from that point, which therefore defines a singularity point where s=1. Also, if a common substrate is provided closer to the viewer, the liquid crystal directors pointing from the edge of the pixel electrode toward the center of the pixel rise toward the center on all projections due to the presence of the oblique electric field of the pixel electrode. Thus, it is possible to produce minor domains, which connect together continuously and smoothly in the projection boundary.

[0097]

FIG. 65 shows a specific example of the means 74 for forming the boundary of alignment. In FIG. 65, the linearly arranged structures are a combination of the projections 32 and the slit structures 44. The means 74 is provided by increasing the width or height of the constituent units 32a of the projections 32 and by increasing the width or depth of

the slit structure 44.

The following Table 2 shows the resultant response speed in comparison with the results of the first embodiment (where the slit width was 10 μm, the projection width was 10 μm and the gap was 20 μm):

Table 2

	1st embodiment	4th embodiment	Driving condition
$T_{ON} + T_{OFF}$	≦25 ms	≦25 ms	0 to 5 V
$T_{ON} + T_{OFF}$	≦50 ms	≦40 ms	0 to 3 V

In this manner, the response speed can be increased thanks to the smooth motion of minor domains on the projections. Thus, it was confirmed that the response speed increased at a gray-scale tone due to the good stability of alignment. In addition, since the width of the electrical connecting portions of the slits can be increased, there is no need to concern about disconnection, which produces a beneficial effect.

[0098]

In the embodiment described above, the units of the projections are supposed to be divided into two as an example. However, the same statement also applies to the bending type. Optionally, several embodiments may be combined together.

FIG. 66 is a plan view showing linear wall structures according to a fifth embodiment of the present invention.

The basic configuration of this liquid crystal display apparatus 10 is similar to that of the liquid crystal display apparatus 10 of the embodiment shown in FIGS. 1, 2 and 5. In the embodiment shown in FIG. 5, the projections (linear wall structure) 30 and 32 extend and bend parallel to each other. According to this arrangement, one pixel includes four areas in which the liquid crystal molecules 16C, 16D, 16E and 16F are aligned in mutually different directions, thereby realizing alignment division along with excellent viewing angle characteristic.

The two line segments forming each bending portion of the projections 30 and 32 define an angle of 90 degrees. The polarizers 26 and 28 are arranged such that their polarization axes form an angle of 45 degrees with respect to the line segments of each bending portion of the projections 30 and 32 as indicated by the reference numeral 48. Although only some of the liquid crystal molecules are shown in FIG. 66, each pixel has four areas in which the liquid crystal molecules 16C, 16D, 16E and 16F (see FIG. 5) are aligned in four different directions.

[0099]

In this embodiment, additional projections 76 and 78 are further provided as additional linear wall structures on the obtuse angle side of the bending portions of the substrates having the projections 30 and 32. More specifically, the

additional projection 76 is arranged on the obtuse angle side of the projection 30 on the upper substrate 12 continuously with the projection 30. The additional projection 76 extends along the bisector of the obtuse angle on that obtuse angle side of the projection 30 on the upper substrate 12. On the other hand, the additional projection 78 is arranged on the obtuse angle side of the projection 32 on the lower substrate 14 continuously with the projection 32. The additional projection 78 extends along the bisector of the obtuse angle on that obtuse angle side of the projection 32 on the lower substrate 14. As a result, the brightness and the response speed both increase.

[0100]

FIG. 67 shows projections 30 and 32 similar to the counterparts shown in FIG. 5. FIG. 67 shows in more detail how the liquid crystal molecules are aligned with respect to the projections 30 and 32. One pixel includes four areas in which the liquid crystal molecules 16C, 16D, 16E and 16F are aligned in four different directions. Furthermore, there is an area of liquid crystal molecules 16G on the obtuse angle side of the bending portion of the projection 30, and there is an area of liquid crystal molecules 16H on the obtuse angle side of the bending portion of the projection 32. When a voltage is applied, the liquid crystal molecules should fall perpendicularly to the projections 30 and 32,

respectively. At the bending portions of the projections 30 and 32, however, the liquid crystal molecules are not controlled by the projections 30, 32 but the liquid crystal molecules 16D-16F and 16C-16E along the two line segments, forming the bending portions, are aligned continuously in a fan pattern. As a result, the liquid crystal molecules 16G and 16H are aligned parallel to the bisector of the obtuse angle at the bending portions of the projections 30 and 32. The direction of alignment of the liquid crystal molecules 16G and 16H is either parallel or perpendicular to the polarization axes indicated by the reference numeral 48. And when a white display state is produced by applying a voltage, the areas of the liquid crystal molecules 16G and 16H become rather dark.

[0101]

FIG. 68 shows a screen on which a white display state is produced on a liquid crystal display apparatus having the linear wall structures shown in FIG. 67. The areas G and H of the liquid crystal molecules 16G and 16H actually darken. Likewise, the areas I at the edges of the pixel electrodes 22 darken, too. This phenomenon will be described more fully later.

In FIG. 66, the additional projections 76 and 78 are provided on the obtuse angle side of the bending portions of the substrates having the projections 30 and 32, and

therefore, the alignment of the liquid crystal molecules 16G and 16H in question is corrected to realize almost the same alignment as that of the liquid crystal molecules 16D-16F and 16C-16E located on both sides thereof. As a result, the areas G and H shown in FIG. 68 do not darken and the brightness increases.

[0102]

The width of the additional projections 76 and 78 may be equal to that of the original projections 30 and 32. Nevertheless, the width of the additional projections 76 and 78 is preferably smaller than that of the original projections 30 and 32. This is because if the additional projections 76 and 78 have an excessive alignment control force, the liquid crystal molecules surrounding the projections 76 and 78 will be aligned perpendicularly to the additional projections 76 and 78. If the additional projections 76, 78 have an insufficient alignment control force on the other hand, the surrounding liquid crystal molecules will not be aligned quite perpendicularly to the additional projections 76 and 78 but will have a similar alignment condition to that of the liquid crystal molecules 16D-16F and 16C-16E located on both sides thereof. If the width of the original projections 30 and 32 is 10 μm, for example, the additional projections 76 and 78 may have a width of about 5 μm.

[0103]

By further providing the additional projections 76 and 78 for the projections 30 and 32 as described above, the liquid crystal molecules at the bending portion can be made to fall just as determined in advance. As a result, both the brightness and the response can be increased.

In this embodiment, the glass substrates 12 and 14 were made of NA-35 with a thickness of 0.7 mm. The pixel electrodes 22 and the common electrode 18 were made of ITO. TFTs, bus lines and so on for driving the liquid crystal layer were arranged on the substrate having the pixel electrodes 22, while color filters were arranged on the counter substrate having the counter electrode 18. A photosensitive acrylic material PC-335 (produced by JSR Corp.) was used as a material for the projections. For both the substrates, the projection width was 10 μm and the projection gap (the distance from the projection end of one substrate to that of the other substrate after the two substrates were bonded together) was 30 μm. The projection height was 1.5 μm. The vertical alignment layers 20, 24 were made of JALS-204 (produced by JSR Corp). A liquid crystal material MJ95785 (produced by Merck & Co., Inc.) was used. Micropearl spacers having a diameter of 3.5 μm (produced by Sekisui Fine Chemical Co., Ltd.) were used as well.

[0104]

FIG. 69 shows a modified example of the linearly arranged structures. In this example, additional projections 76x and 78x are arranged on the acute angle side of the bending portions of the projections 30 and 32. In this case, the direction of alignment of liquid crystal molecules defined by the projections 30, 32 is not quite continuous with that of liquid crystal molecules defined by the additional projections 76x and 78x. Instead, the liquid crystal molecules in the vicinity of the bending portions of the projections 30 and 32 face a direction that is perpendicular to the polarization axes, thus resulting in insufficient improvement. Consequently, it was discovered that the additional projections 76x and 78x should be provided on the obtuse angle side of the bending portions of the projections 30 and 32 as shown in FIG. 66.

[0105]

The additional projections 76 and 78 have been described as being viewed from the same substrate as the one provided with the projections 30 or 32. However, when viewed from the substrate that faces the one provided with the projections 30 or 32, the additional projections 76 and 78 will look as follows. In FIG. 66, for example, the additional projection 76 is provided on the acute angle side of the bending portion of the projection 32 on the substrate 14 that faces the

substrate 12 with the projections 30 (see claim 34). Likewise, the additional projection 78 is provided on the acute angle side of the bending portion of the projection 30 on the substrate 12 that faces the substrate 14 with the projections 32.

[0106]

FIG. 70 shows a modified example of the linearly arranged structures. In this example, the additional projections 76x and 78x are provided on the obtuse angle side of the bending portions of the projections 30 and 32 as in the example shown in FIG. 66. The additional projections 76x and 78x of this example extend farther than the projections 76x and 78x shown in FIG. 66. The far end of each additional projection 76x or 78x reaches a point where it overlaps with the bending portion of the projection 32 or 30 facing the additional projection 76x or 78x. The additional projections 76 and 78 may be extended in this way but should not be extended beyond the point where the far end thereof overlaps with the bending portion of the projection 32 or 30.

[0107]

Furthermore, in this example, the upper substrate 12 and the lower substrate provided with these projections 32 and 30 and additional projections 76x and 78x are bonded together with their peripheries sealed to make an empty panel, into which a liquid crystal material is injected after that. In

this example, the projections have a height of 1.75 μm, and the projections on the two substrates partially contact with each other to achieve a cell thickness of 3.5 μm. The cell thickness was maintained by making the projections on the two substrates partially contact with each other without using any spacers. If there were spacers, the orientations of liquid crystal molecules would also change on the surfaces of the spacers. However, since no spacers are dispersed, there are no abnormal orientations that might otherwise be caused by the spacers.

[0108]

As described above, the linear wall alignment control structures consist of the projections 30 and 32 or the slit structures 44 and 46. Accordingly, if the slit structures 44 and 46 are adopted as the linear wall structures, additional slit structures similar to the slit structures 44 and 46 may be provided instead of the additional projections 76x and 78x. Also, the linear wall alignment control structures may also be formed by cutting a slit through an electrode and providing a projection thereon.

[0109]

FIG. 71 shows a modified example of the linear wall structures. As the linear wall alignment control structures, the projections 30 of the upper substrate 12 and the slit structures 46 of the lower substrate 14 are provided. As

described above, the slit structures 46 are made by cutting slits through the pixel electrodes 22 of the lower substrate 14. The additional projection 76 is provided just like the additional projection 76 shown in FIG. 66, and an additional slit structure 78y is provided on the obtuse angle side of the bending portion of the slit structure 46 instead of the additional projection 78 shown in FIG. 66. The additional slit structure 78y is not continuous with the bending portion of the slit structure 46 because the slit structure 46 is designed as a slit that has been cut through the pixel electrode 22 and has a discontinuous portion. The additional slit structure 78y may be regarded as being provided on the acute angle side of the projection 30 of the counter substrate.

[0110]

FIG. 72 shows a modified example of the linear wall structures. In this example, the additional projections 76 and 78 are provided as in the example shown in FIG. 66. Furthermore, edge projections 80 are provided so as to overlap with at least portions of the edges of the pixel electrode 22. In this case, the projections 30 and 32 are neither parallel nor perpendicular to the edges of the pixel electrode 22. The edge projections 80 are arranged in areas corresponding to the areas I shown in FIG. 68. As shown in FIG. 67, the liquid crystal molecules at the edges of the

pixel electrode 22 are aligned in such a manner as to fall toward the center of the pixel due to the effect of the oblique electric field. In the areas corresponding to the areas I shown in FIG. 68, the projection 30 on the upper substrate (counter substrate) 12 and the edge of the pixel electrode 22 form an obtuse angle. Or the projection 32 on the pixel electrode 22 and the edge of the pixel electrode 22 define an acute angle.

[0111]

In these areas, the alignment of liquid crystal molecules is quite different from that of liquid crystal molecules located inside the edges (see FIG. 67), and therefore, the display darkens as shown in FIG. 68. However, by providing the edge projections 80 as shown in FIG. 72, the alignment of the liquid crystal molecules around the edges of the pixel electrode 22 becomes closer to that of the liquid crystal molecules located inside those edges, thereby preventing the display from darkening. In FIG. 72, corner projections 82 are also provided.

[0112]

FIG. 73 shows a modified example of the linear wall structures. This modified example is similar to the example shown in FIG. 72 except that no corner projections 82 are provided in this modified example. Also, in the examples illustrated in FIGS. 72 and 73, newly provided projections

are extended to the projections on the pixel electrode. The projections had a height of 1.75 μm and no spacers were dispersed. A cell thickness of 3.5 μm was achieved by making the projections on the two substrates partially contact with each other.

[0113]

FIG. 74 shows a modified example of the linear wall structures. In this modified example, the projection 30 has an additional projection 76, the slit structure 46 has an additional slit structure 78y, and the projection 30 and the slit structure 46 consist of a plurality of constituent units (30S and 46S) as in the example shown in FIG. 21. Thus, in this case, the effect achieved by making the linear wall structure up of a plurality of constituent units and the effect achieved by providing an additional linear wall structure are both attained.

[0114]

[Effects of the Invention]

As described above, according to the present invention, a liquid crystal display apparatus that has increased brightness and increased response speed can be fabricated. In addition, the orientation directions of all domains that have been formed on linear wall structures can be aligned with each other and the variations of the domains with time can be reduced significantly, thus eliminating the overshoot

phenomenon.

[Brief Description of the Drawings]

[FIG. 1]

A schematic cross-sectional view showing a liquid crystal display apparatus.

[FIG. 2]

A schematic cross-sectional view showing a vertical alignment type liquid crystal display apparatus having linear wall structures for controlling alignment of liquid crystal molecules.

[FIG. 3]

A plan view showing one pixel and linear wall structures.

[FIG. 4]

Views illustrating how liquid crystal molecules fall due to the presence of the linear wall structures shown in FIGS. 2 and 3 when a voltage is applied thereto.

[FIG. 5]

A plan view showing another example of linear wall structures.

[FIG. 6]

A schematic cross-sectional view showing a liquid crystal display apparatus in which the linear wall structures of both substrates are projections.

[FIG. 7]

A schematic cross-sectional view showing a liquid crystal apparatus in which the linear wall structures of one of the two substrates are projections and the linear wall structures of the other substrate are slit structures.

[FIG. 8]

A schematic cross-sectional view showing a liquid crystal display apparatus in which the linear wall structures of both substrates are slit structures.

[FIG. 9]

A cross-sectional view showing exemplary linear wall structures in the form of projections.

[FIG. 10]

A cross-sectional view showing exemplary linear wall structures in the form of slit structures.

[FIG. 11]

A view showing an alignment problem of a liquid crystal display apparatus with linear wall structures.

[FIG. 12]

A graph showing transmittances in several areas shown in FIG. 11.

[FIG. 13]

A graph showing the overshoot of brightness.

[FIG. 14]

A view showing exemplary linear wall structures according to a first embodiment of the present invention.

[FIG. 15]

A view showing a modified example of the linear wall structures.

[FIG. 16]

A view showing another modified example of the linear wall structures.

[FIG. 17]

A view showing another modified example of the linear wall structures.

[FIG. 18]

A view showing another modified example of the linear wall structures.

[FIG. 19]

A view showing another modified example of the linear wall structures.

[FIG. 20]

A view showing another modified example of the linear wall structures.

[FIG. 21]

A view showing another modified example of the linear wall structures.

[FIG. 22]

A view showing the pixel electrode and the slit structures shown in FIG. 22.

[FIG. 23]

Views showing how to form the linear wall structures as projections.

[FIG. 24]

A view showing the alignment of liquid crystal molecules in a liquid crystal display apparatus having linear wall structures.

[FIG. 25]

Shows the display characteristic of the arrangement shown in FIG. 24.

[FIG. 26]

A view showing how liquid crystal molecules are aligned in a liquid crystal display apparatus having linear wall structures including a plurality of constituent units.

[FIG. 27]

Shows the display characteristic of the arrangement shown in FIG. 26.

[FIG. 28]

A view showing the alignment of liquid crystal molecules in a liquid crystal display apparatus having linear wall structures according to a second preferred embodiment of the present invention.

[FIG. 29]

Shows the display characteristic of the arrangement shown in FIG. 28.

[FIG. 30]

Shows the features of the boundaries of alignment of first and second types.

[FIG. 31]

A plan view showing a specific example of the linear wall structures shown in FIG. 28.

[FIG. 32]

A cross-sectional view of the linear wall structures shown in FIG. 31.

[FIG. 33]

A plan view showing a modified example of the linear wall structures.

[FIG. 34]

A cross-sectional view of the linear wall structures shown in FIG. 33.

[FIG. 35]

Plan views showing modified examples of the linear wall structures.

[FIG. 36]

A plan view showing another modified example of the linear wall structures.

[FIG. 37]

A plan view showing another modified example of the linear wall structures.

[FIG. 38]

A cross-sectional view showing an edge of a pixel

electrode of the liquid crystal display apparatus and its surrounding portions.

[FIG. 39]

Shows the alignment of liquid crystal molecules at the edge of the pixel electrode shown in FIG. 38.

[FIG. 40]

A plan view showing another modified example of the linear wall structures.

[FIG. 41]

A plan view showing another modified example of the linear wall structures.

[FIG. 42]

A plan view showing another modified example of the linear wall structures.

[FIG. 43]

A plan view showing linear wall structures according to a third embodiment of the present invention.

[FIG. 44]

A cross-sectional view of the liquid crystal display apparatus showing a cross section of the linear wall structures shown in FIG. 43.

[FIG. 45]

A view showing the alignment of liquid crystal molecules near the linear wall structures shown in FIG. 44.

[FIG. 46]

A view showing the alignment of liquid crystal molecules near the linear wall structures of the first embodiment.

[FIG. 47]

A cross-sectional view showing a modified example of the linear wall structure and the means for controlling the boundary alignment.

[FIG. 48]

A cross-sectional view showing a modified example of the linear wall structure and the means for controlling the boundary alignment.

[FIG. 49]

A cross-sectional view showing a modified example of the linear wall structure and the means for controlling the boundary alignment.

[FIG. 50]

A cross-sectional view showing a modified example of the linear wall structure and the means for controlling the boundary alignment.

[FIG. 51]

A plan view showing a modified example of the linear wall structure and the means for controlling the boundary alignment.

[FIG. 52]

A cross-sectional view as viewed on the plane 52-52 shown in FIG. 51.

[FIG. 53]

A cross-sectional view as viewed on the plane 53-53 shown in FIG. 51.

[FIG. 54]

A plan view showing a modified example of the linear wall structure and the means for controlling the boundary alignment.

[FIG. 55]

A cross-sectional view of a liquid crystal display apparatus showing a cross section of the linear wall structures shown in FIG. 54.

[FIG. 56]

A plan view showing a modified example of the linear wall structure and the means for controlling the boundary alignment.

[FIG. 57]

A cross-sectional view of a liquid crystal display apparatus showing a cross section of the linear wall structures shown in FIG. 56.

[FIG. 58]

A plan view showing linear wall structures according to a fourth embodiment of the present invention.

[FIG. 59]

A schematic cross-sectional view of the liquid crystal display apparatus as viewed on the plane 59-59 in FIG. 58.

[FIG. 60]

A plan view showing another modified example of the linear wall structures.

[FIG. 61]

A plan view showing a pixel electrode with the slit structures shown in FIG. 60.

[FIG. 62]

A plan view showing another modified example of the linear wall structures.

[FIG. 63]

A plan view showing another modified example of the linear wall structures.

[FIG. 64]

A plan view showing another modified example of the linear wall structures.

[FIG. 65]

A plan view showing another modified example of the linear wall structures.

[FIG. 66]

A plan view showing linear wall structures according to a fifth embodiment of the present invention.

[FIG. 67]

A plan view showing typical examples of linear wall structures with bending portions.

[FIG. 68]

A view pointing out the problems of a liquid crystal display apparatus with the linear wall structures shown in FIG. 67.

[FIG. 69]

A plan view showing another modified example of the linear wall structures.

[FIG. 70]

A plan view showing another modified example of the linear wall structures.

[FIG. 71]

A plan view showing another modified example of the linear wall structures.

[FIG. 72]

A plan view showing another modified example of the linear wall structures.

[FIG. 73]

A plan view showing another modified example of the linear wall structures.

[FIG. 74]

A plan view showing another modified example of the linear wall structures.

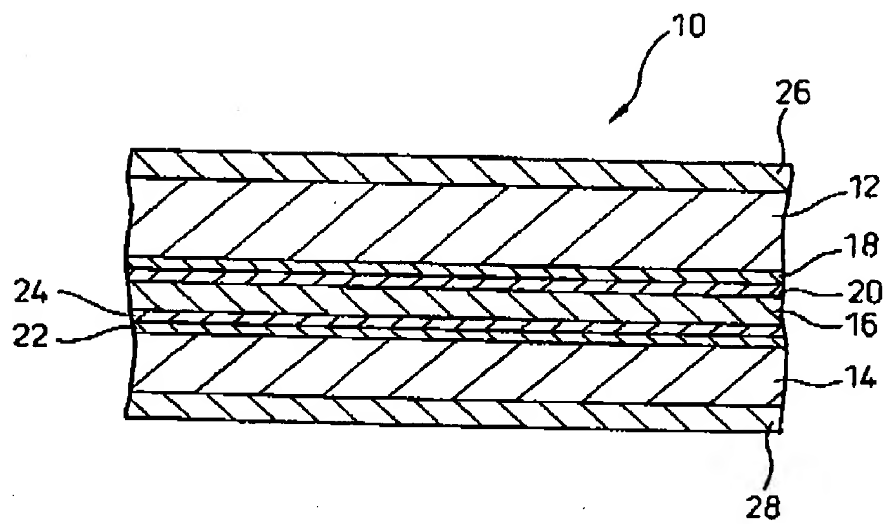
[Description of the Reference Numerals]

12, 14	substrate
16	liquid crystal material
18, 22	electrode

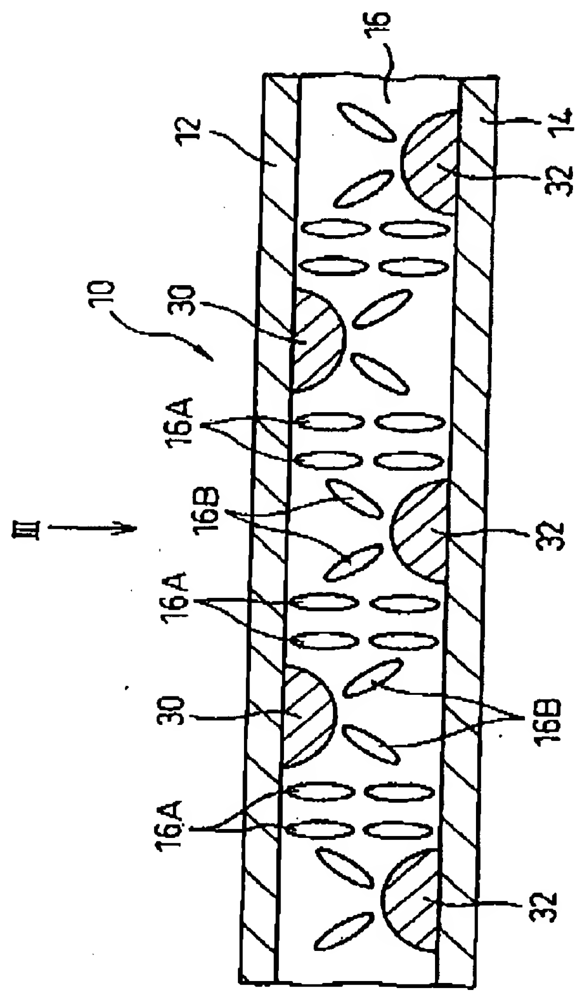
20, 24	vertical alignment layer
26, 28	polarizer
30, 32	linear wall structure (projection)
30S, 32S	constituent unit
42	oblique electric field
44, 46	linear wall structure (slit structure)
44S, 46S	constituent unit

[Name of Document] Drawings

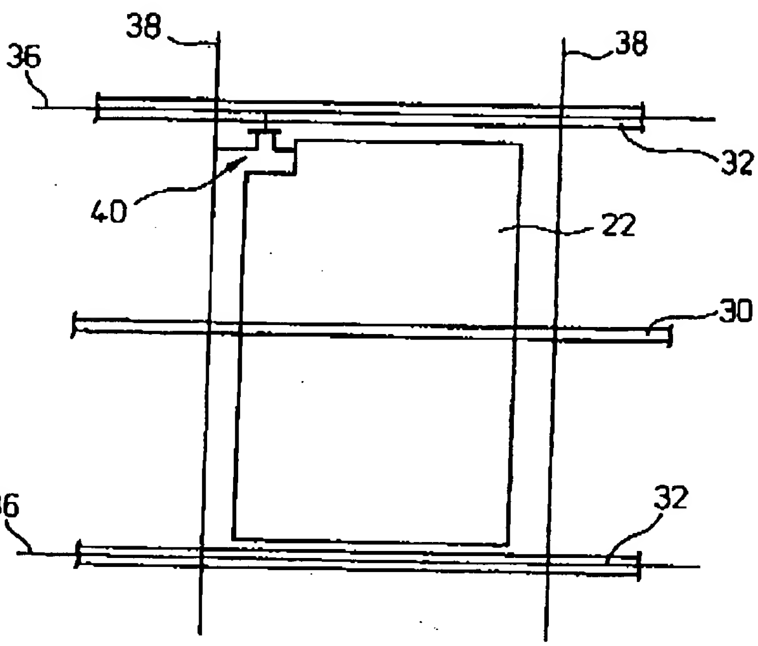
[Fig.1]



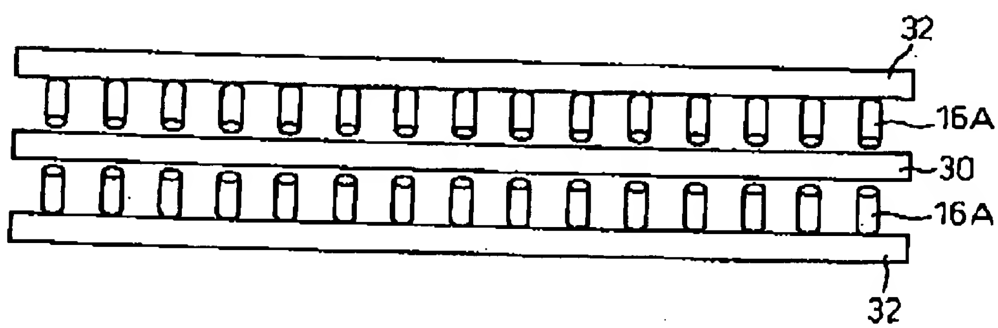
[Fig.2]



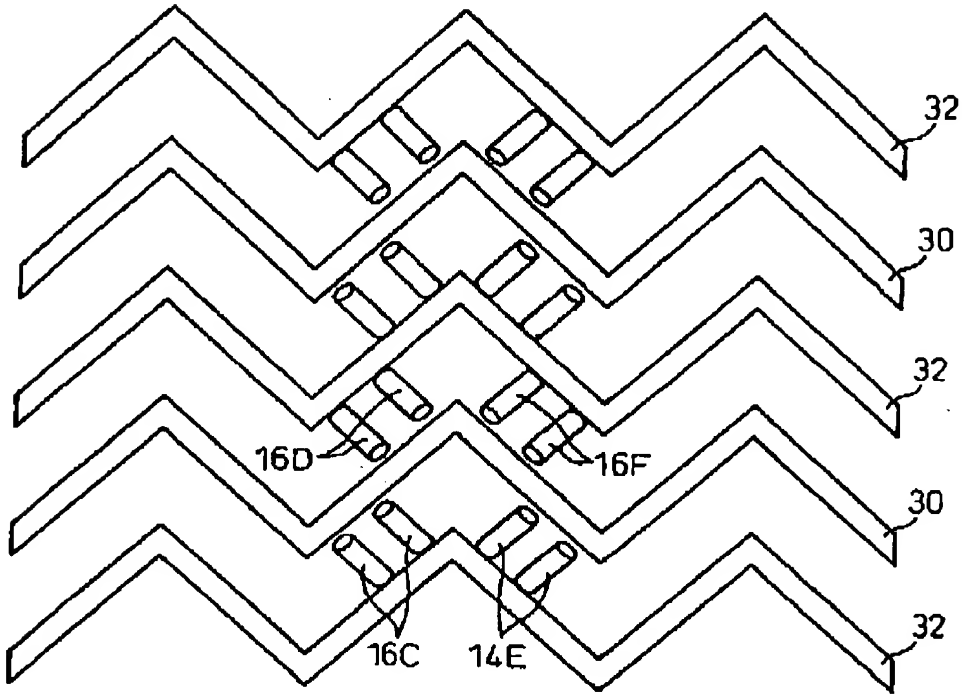
[Fig.3]



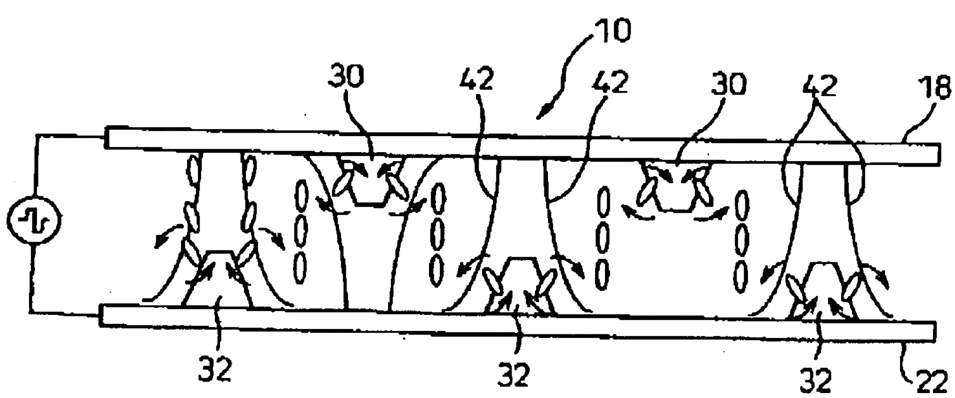
[Fig.4]



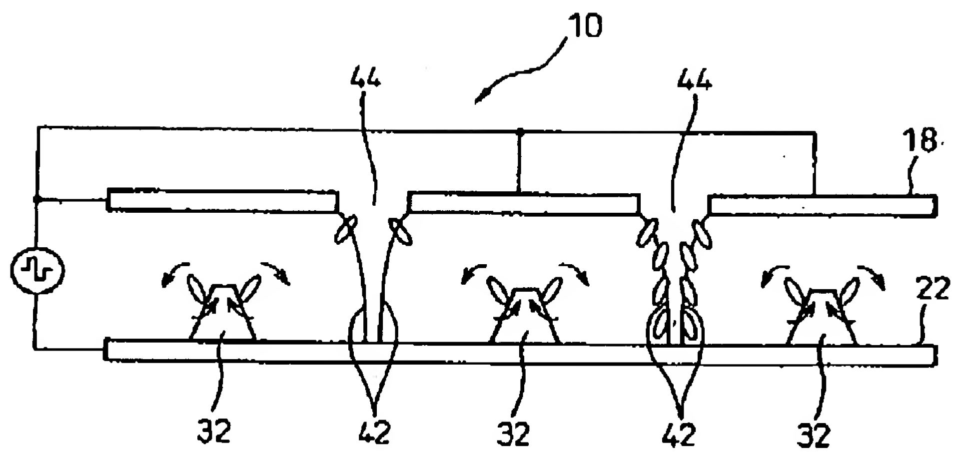
[Fig.5]



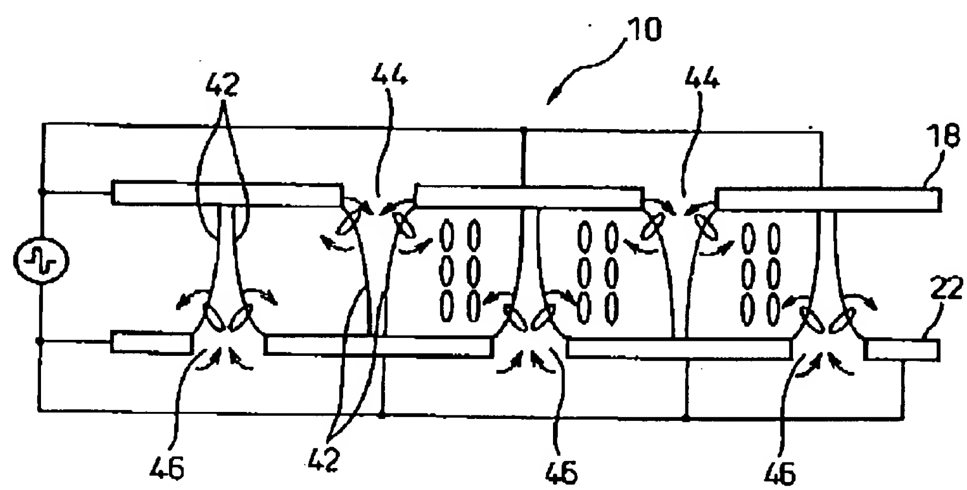
[Fig.6]



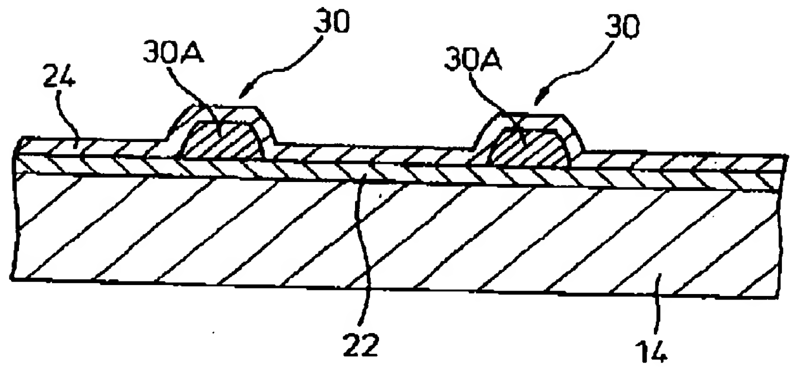
[Fig.7]



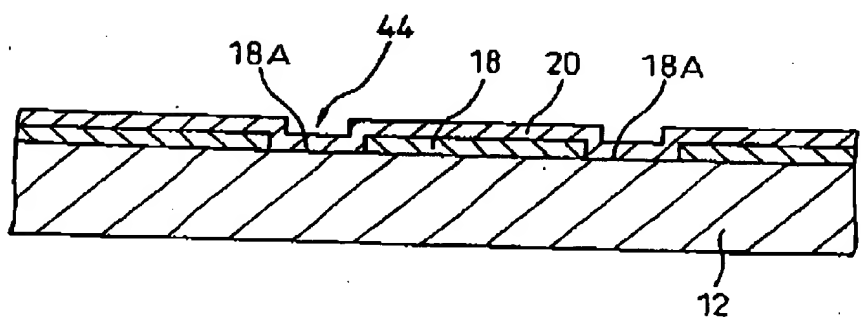
[Fig.8]



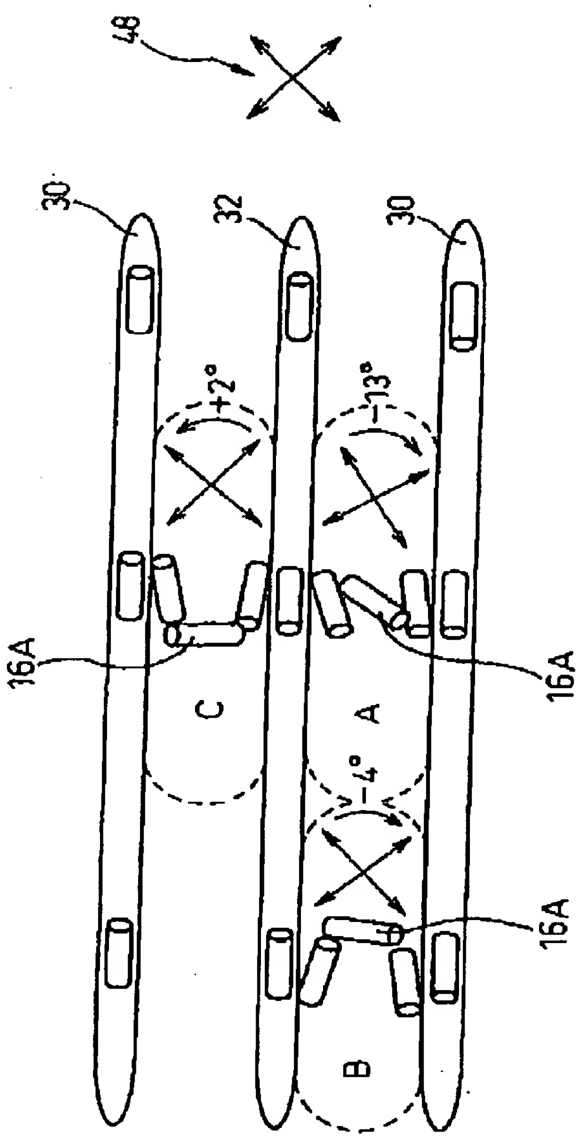
[Fig.9]



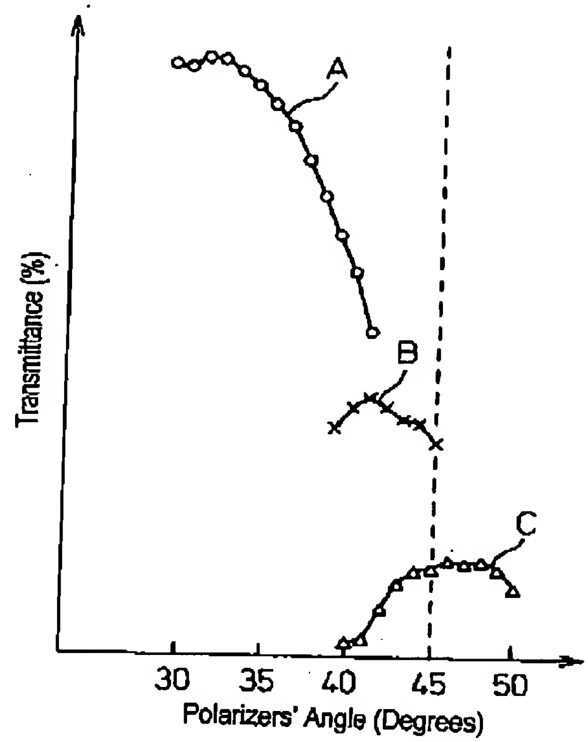
[Fig.10]



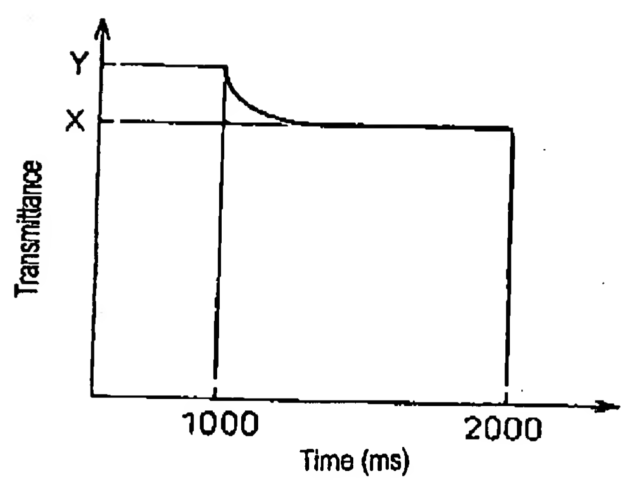
[Fig.11]



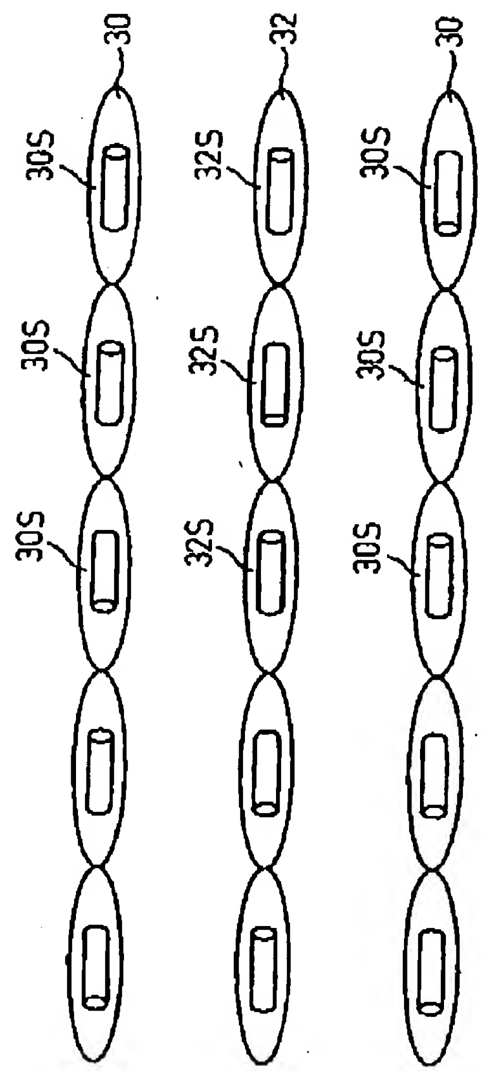
[Fig.12]


A
B
C
Transmittance (%)
30
35
40
45
50
Polarizers' Angle (Degrees)

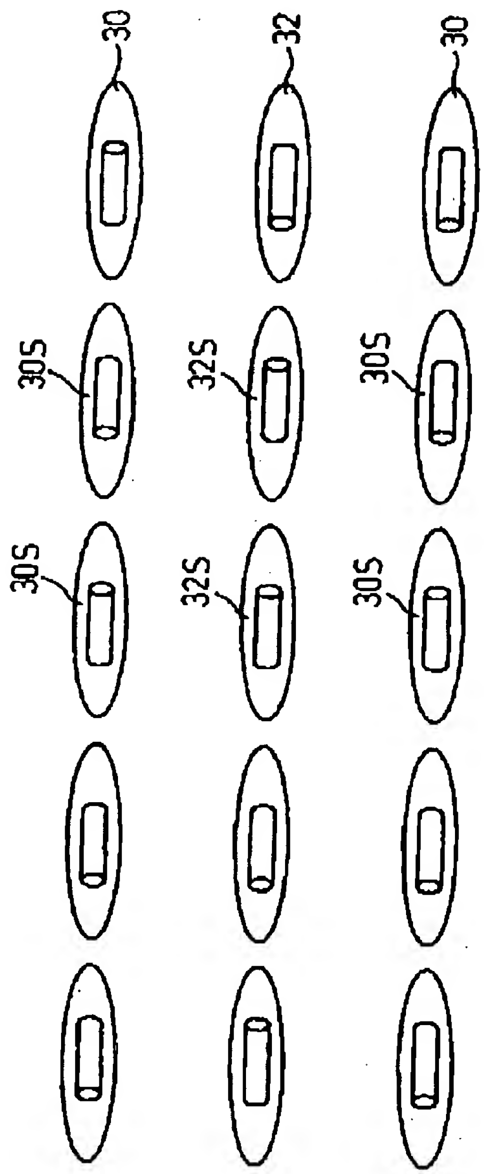
[Fig.13]


Y
X
Transmittance
1000
2000
Time (ms)

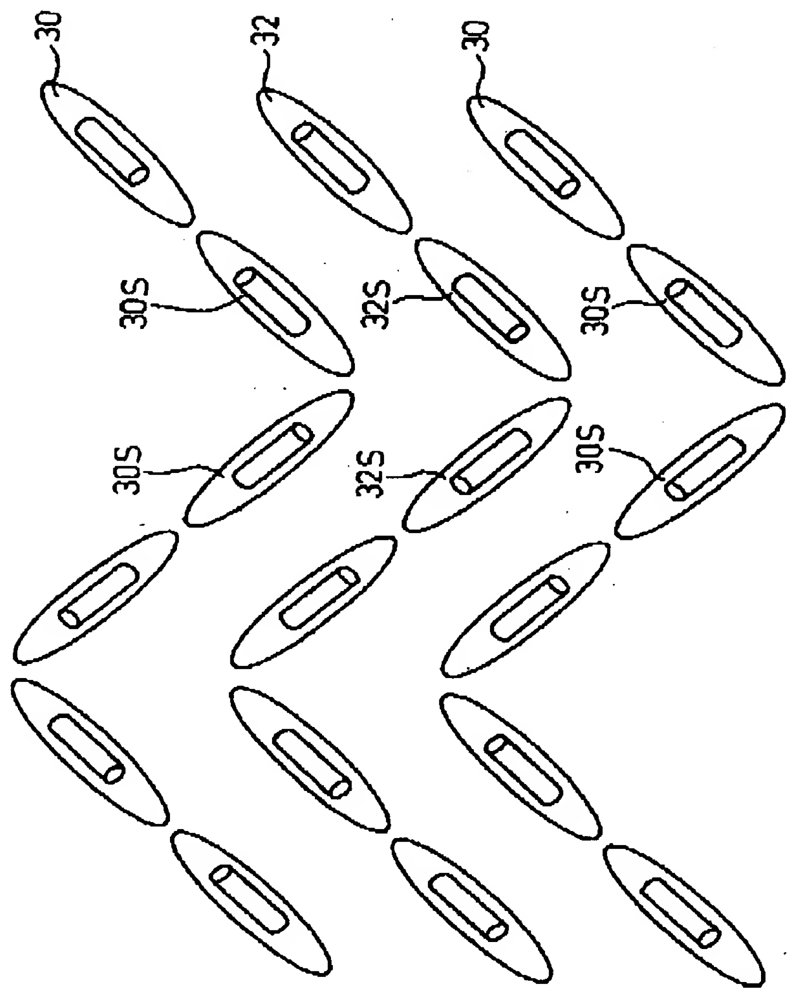
[Fig.14]



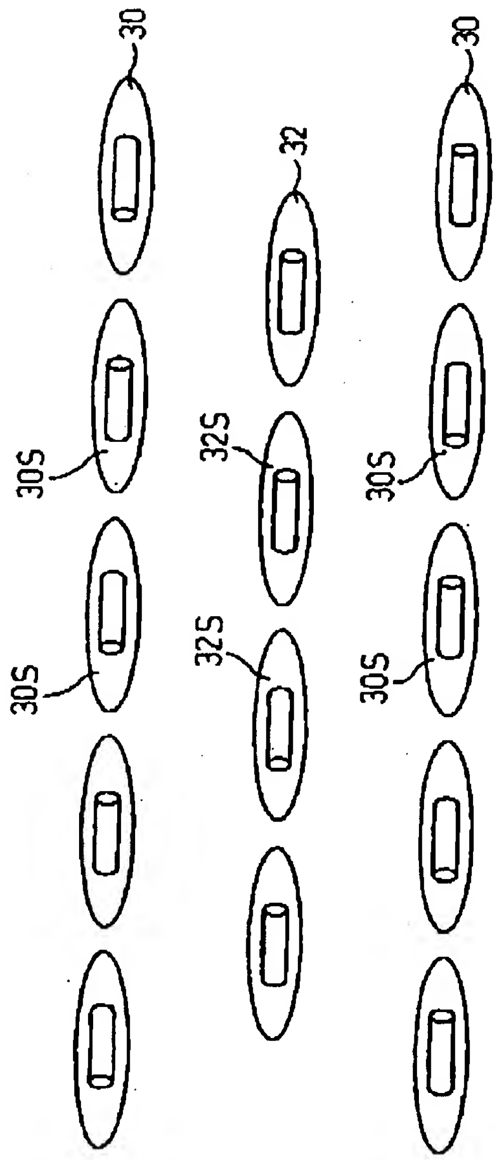
[Fig.15]



[Fig.16]



[Fig.17]



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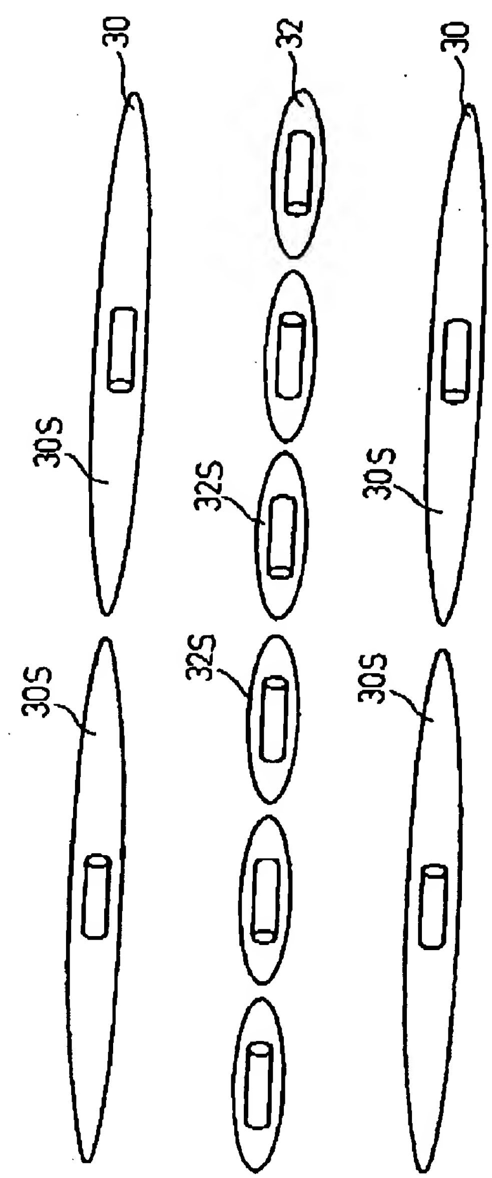
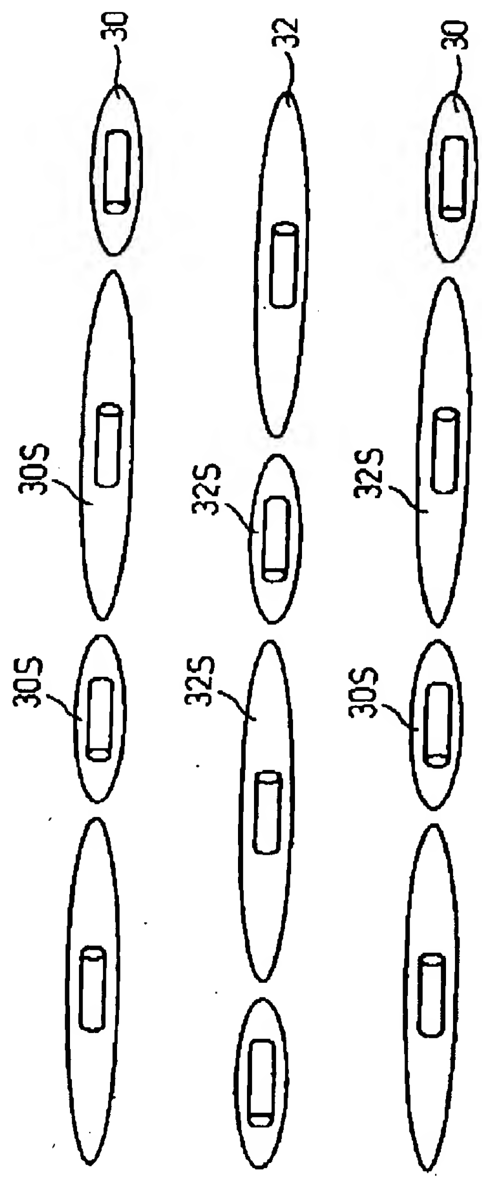
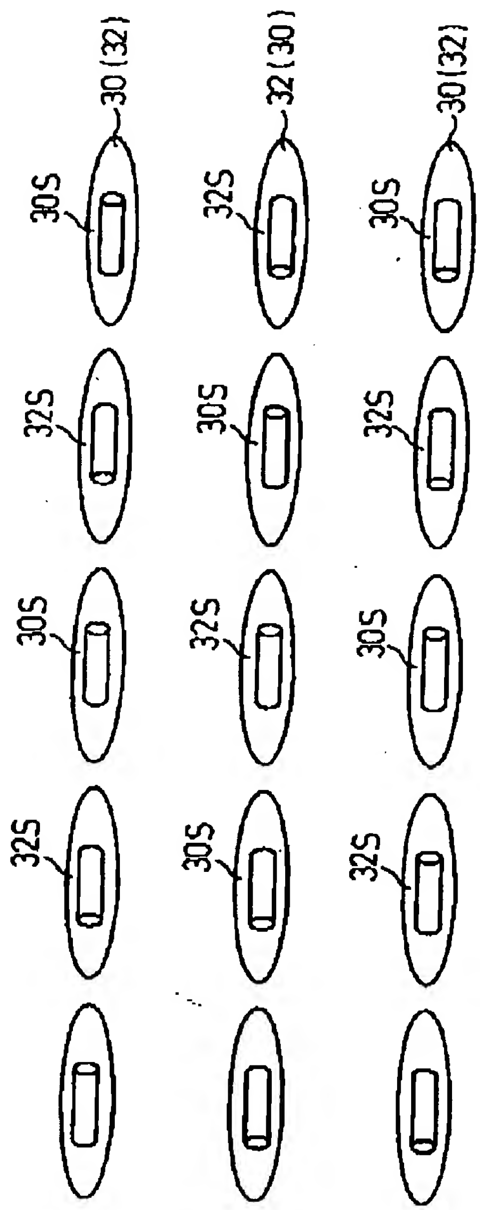
[Fig.18]



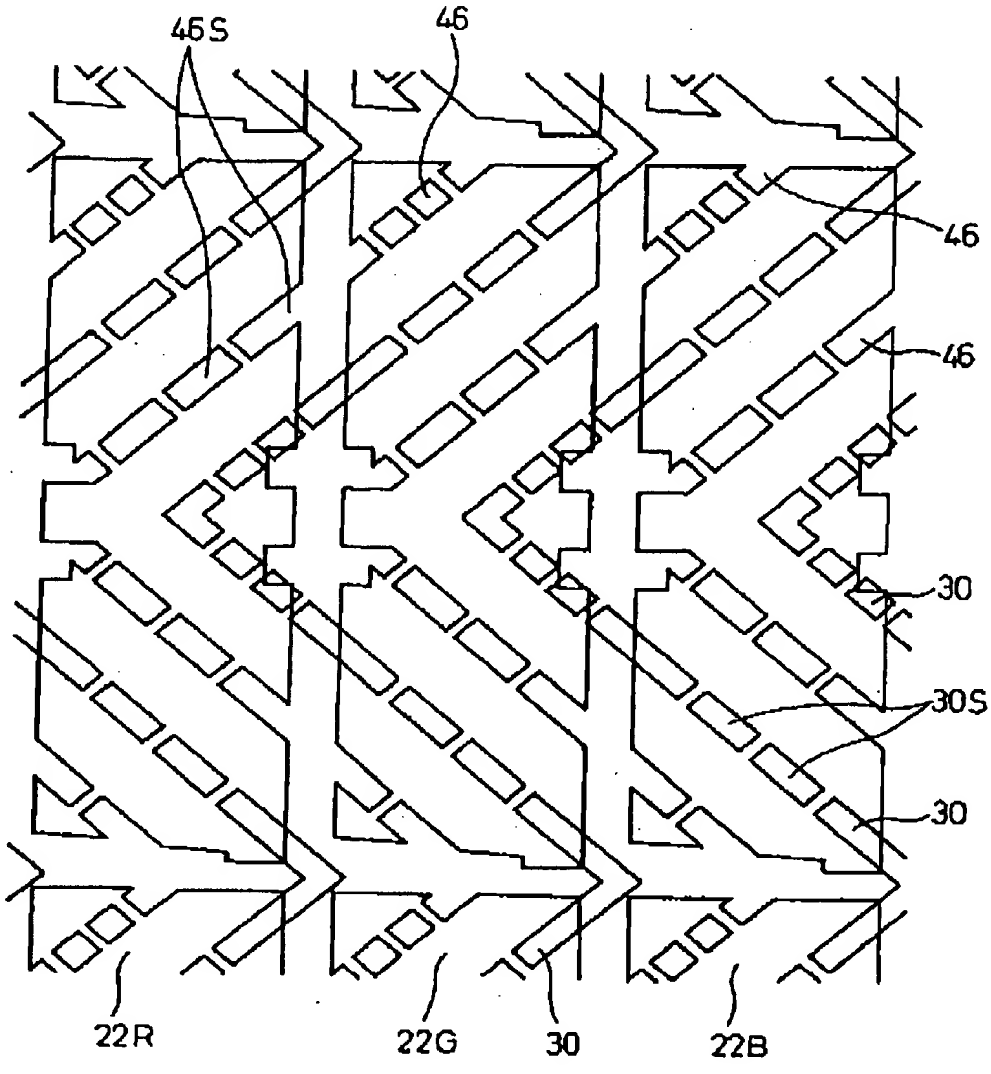
[Fig.19]



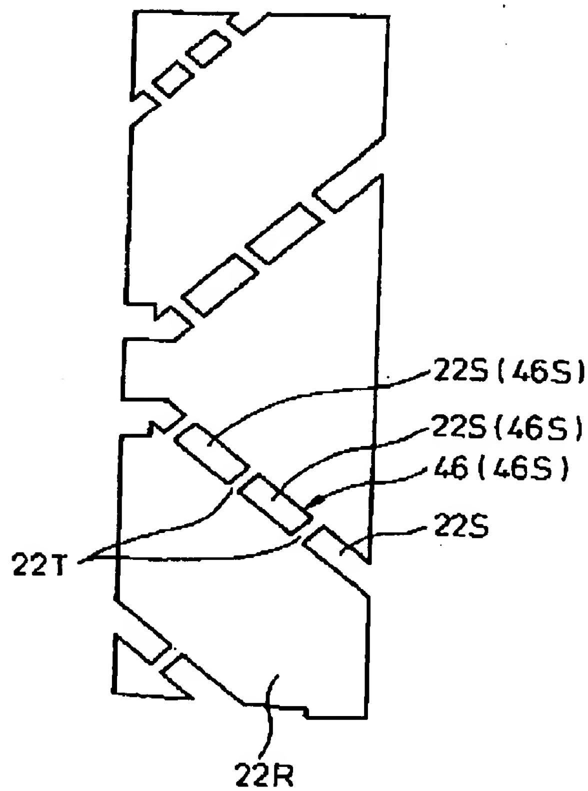
[Fig.20]



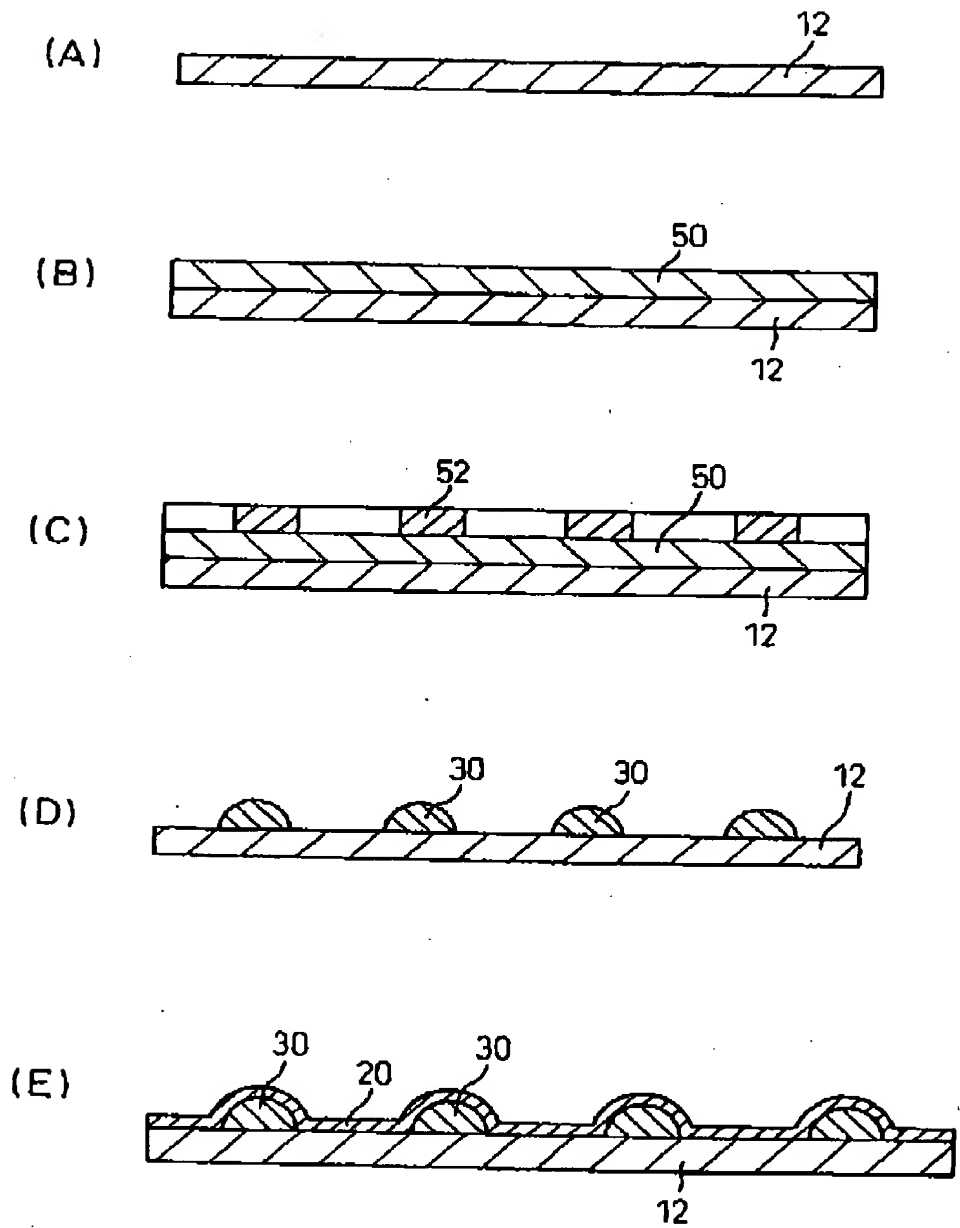
[Fig.21]



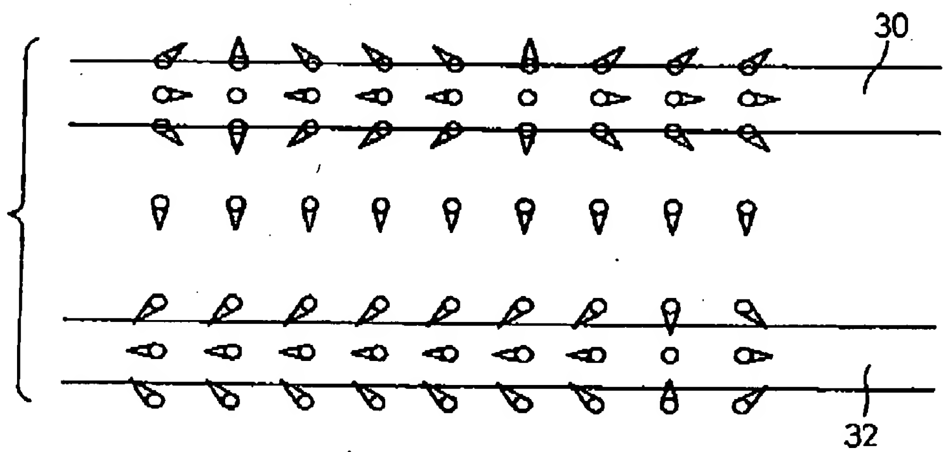
[Fig.22]



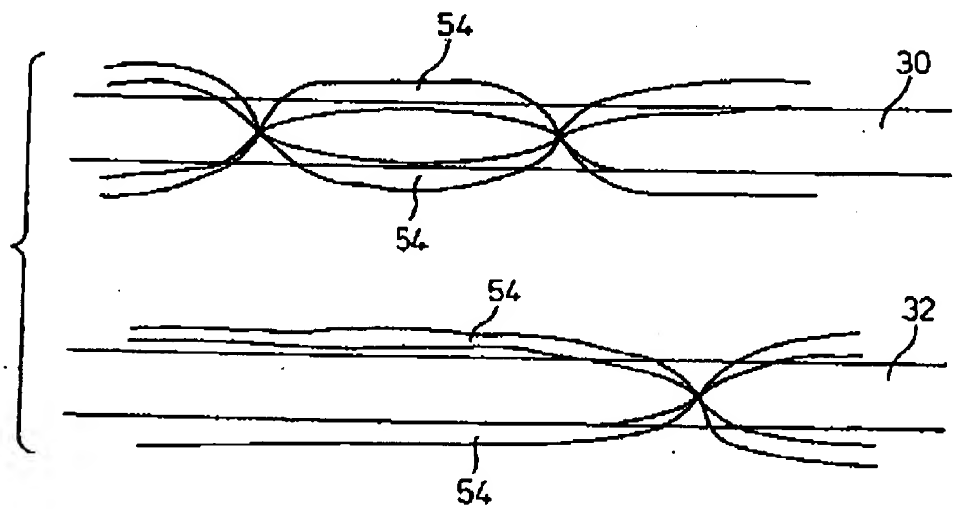
[Fig.23]



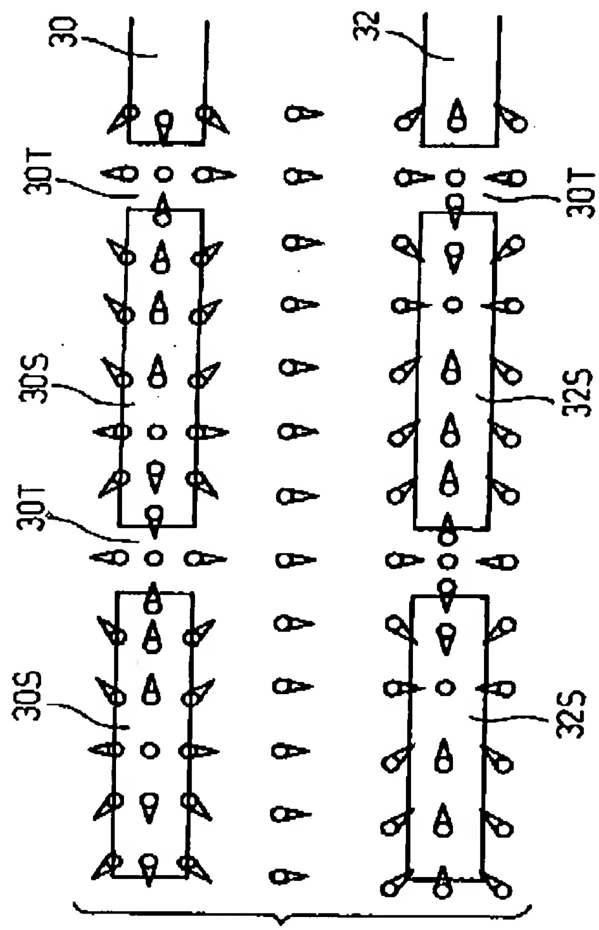
[Fig.24]



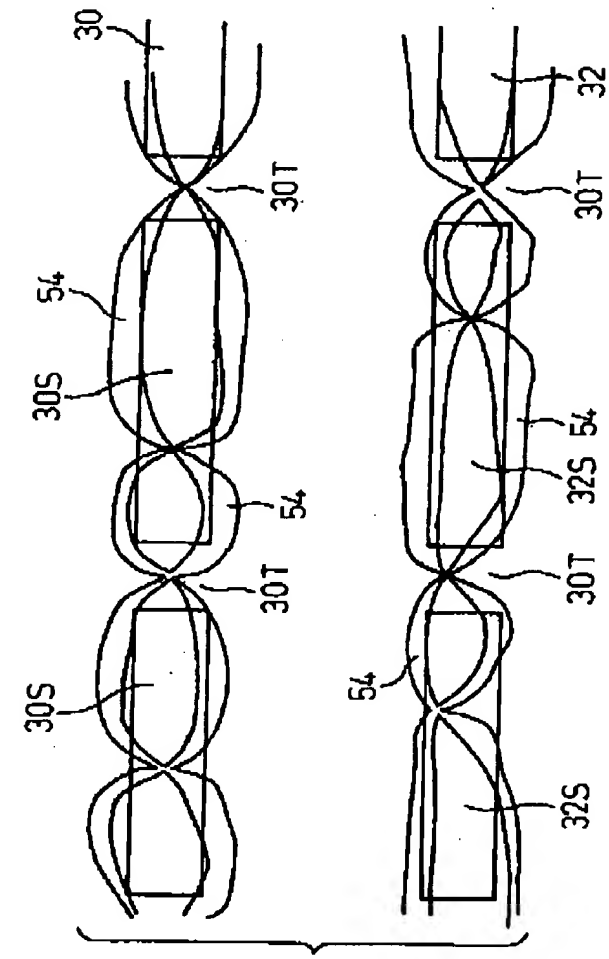
[Fig.25]



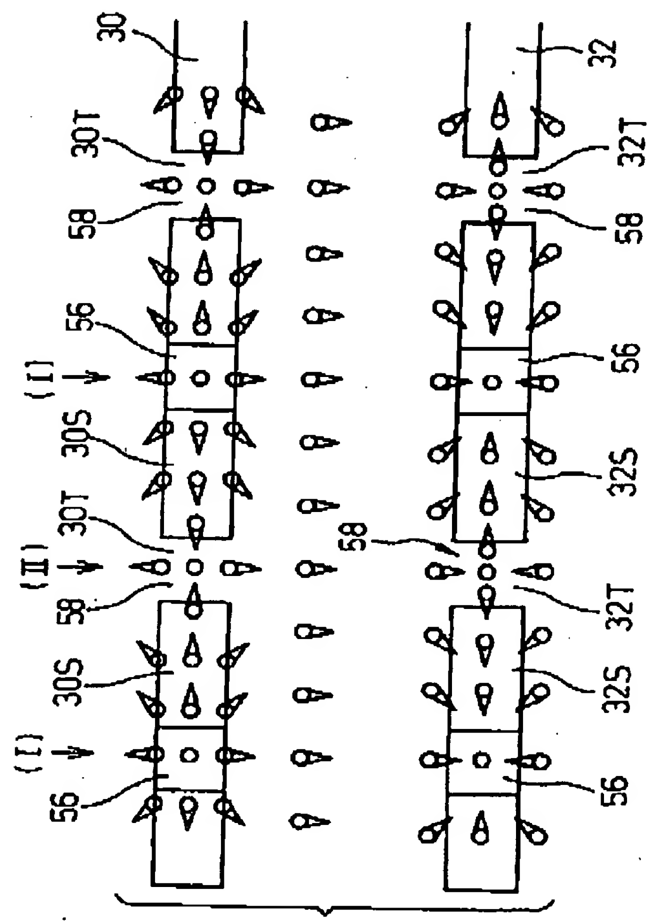
[Fig.26]



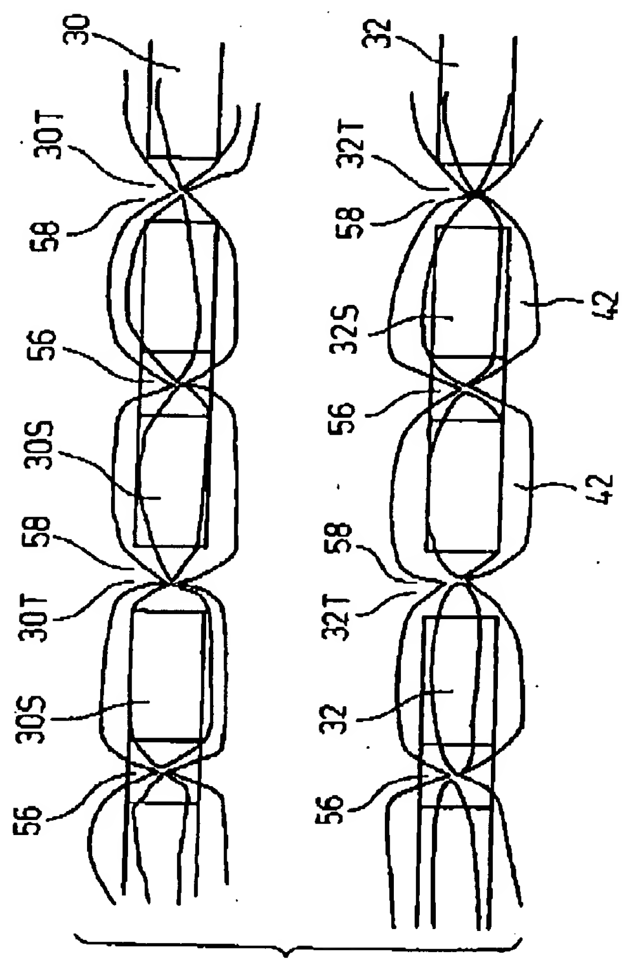
[Fig.27]



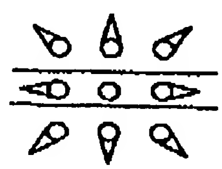
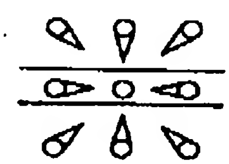
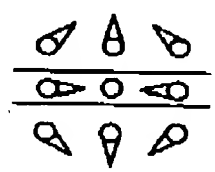
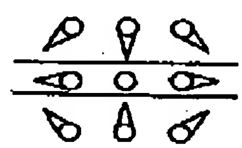
[Fig.28]



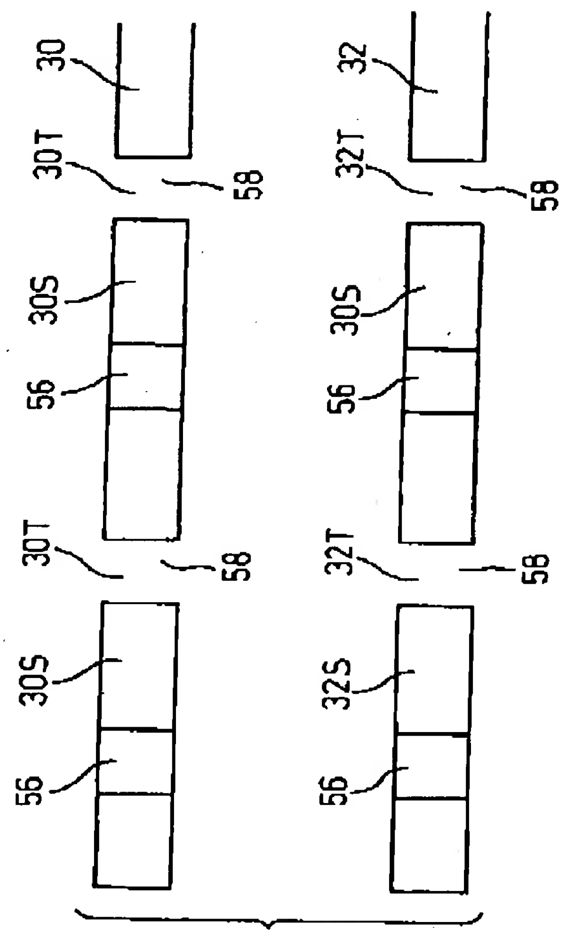
[Fig.29]



[Fig.30]

Type	Features	
	When Viewed From Over Projection	When Viewed From Under Projection
(I)		
(II)		

[Fig.31]



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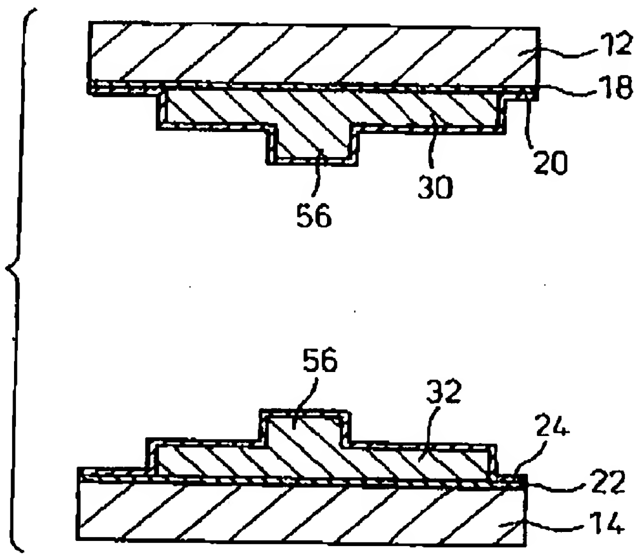
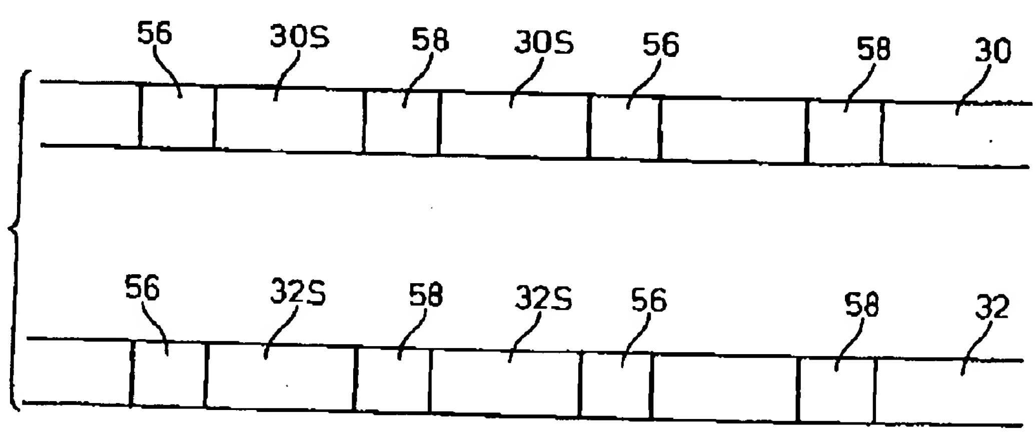
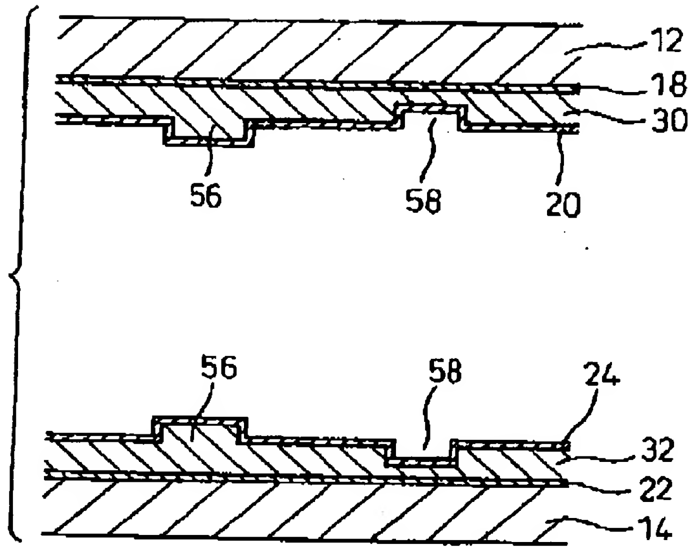
[Fig.32]



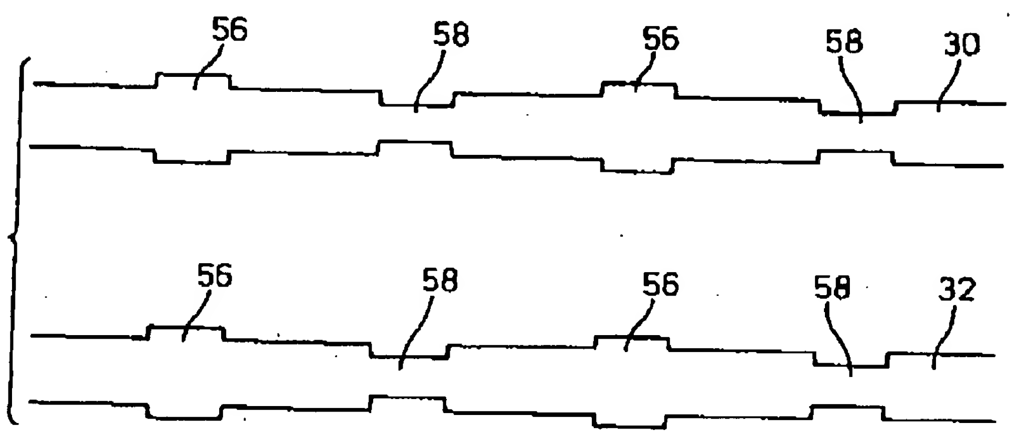
[Fig.33]



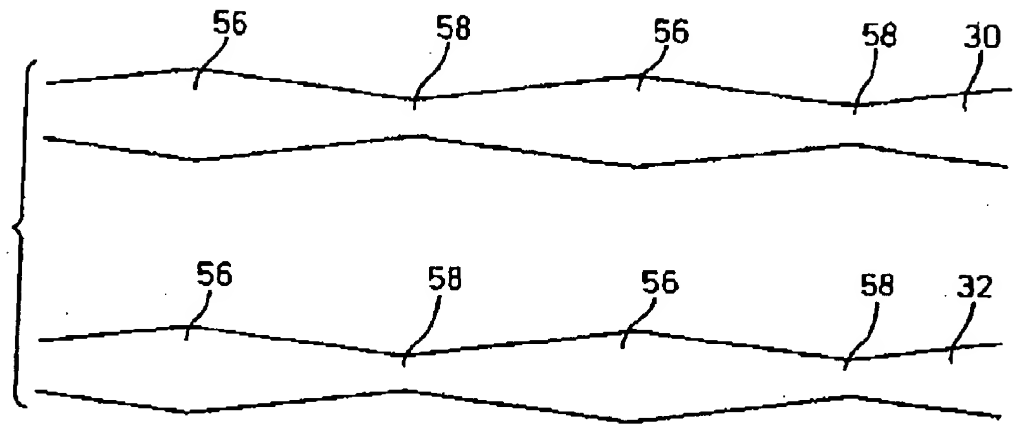
[Fig.34]



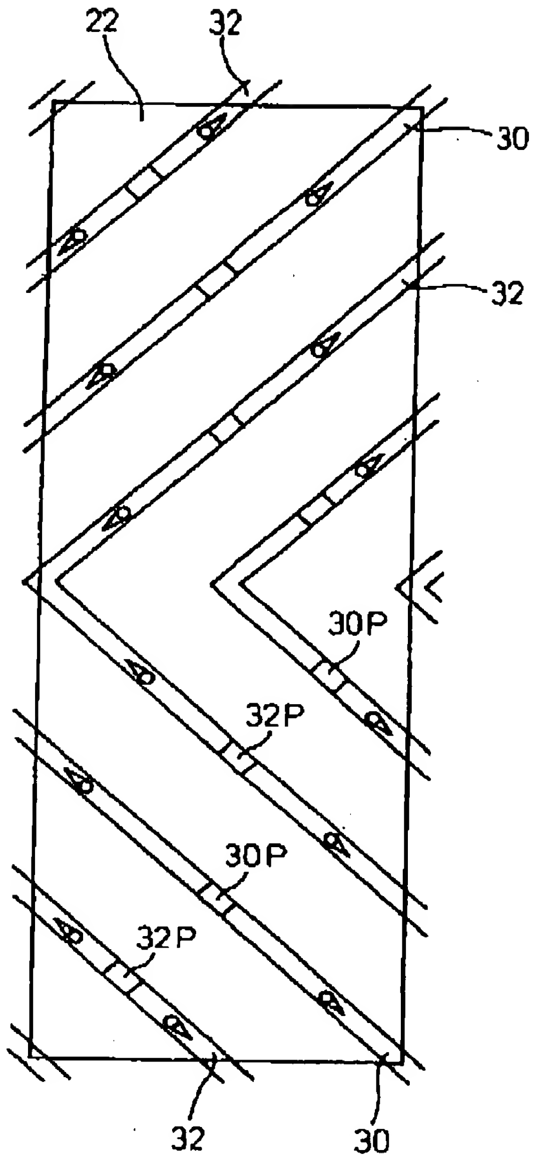
[Fig.35]



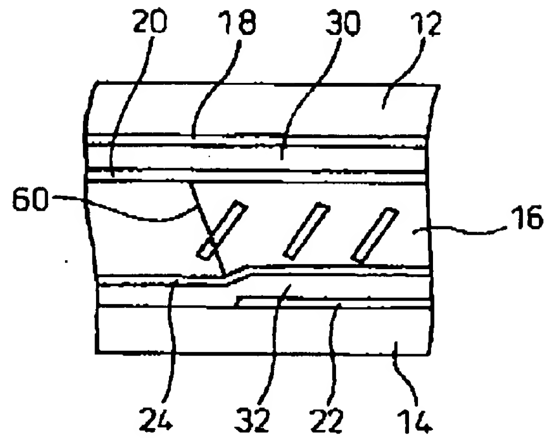
[Fig.36]



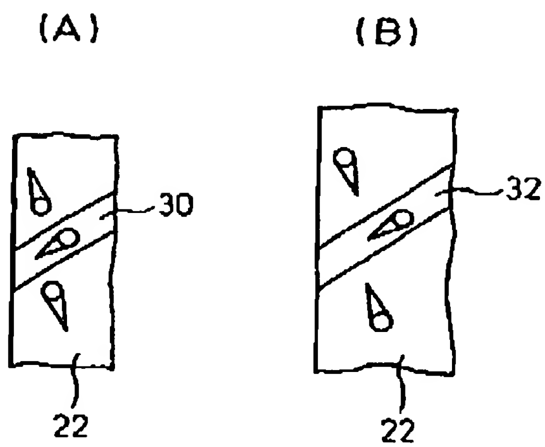
[Fig.37]



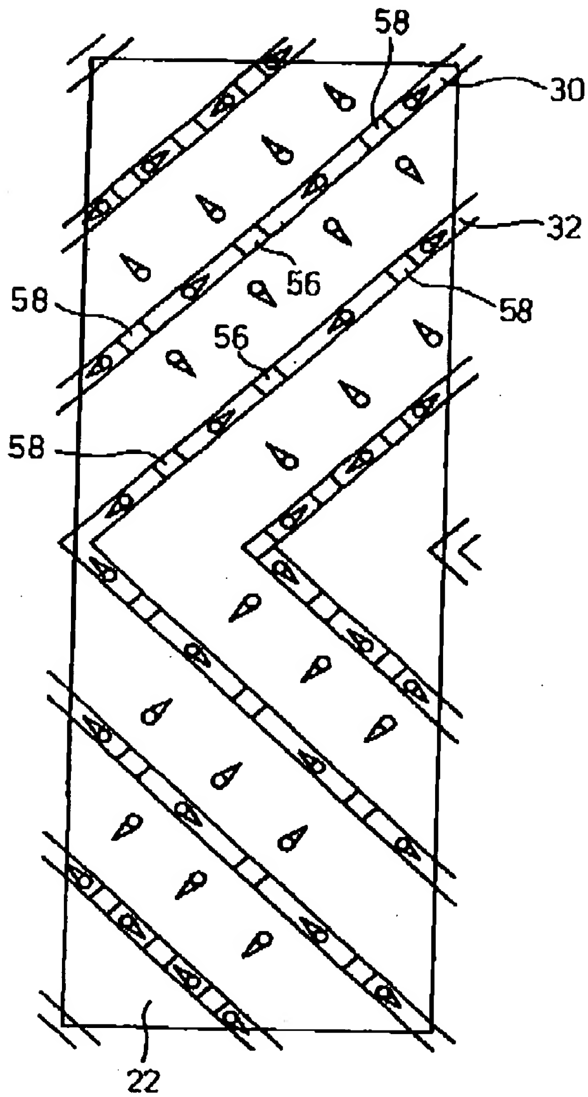
[Fig.38]



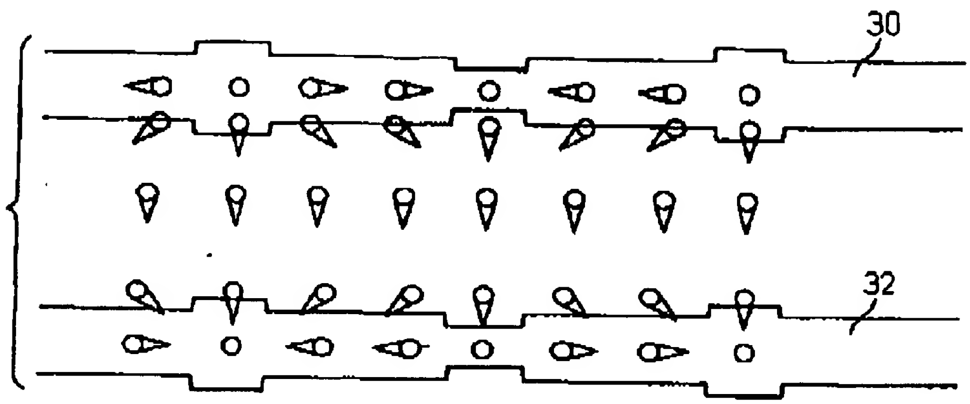
[Fig.39]



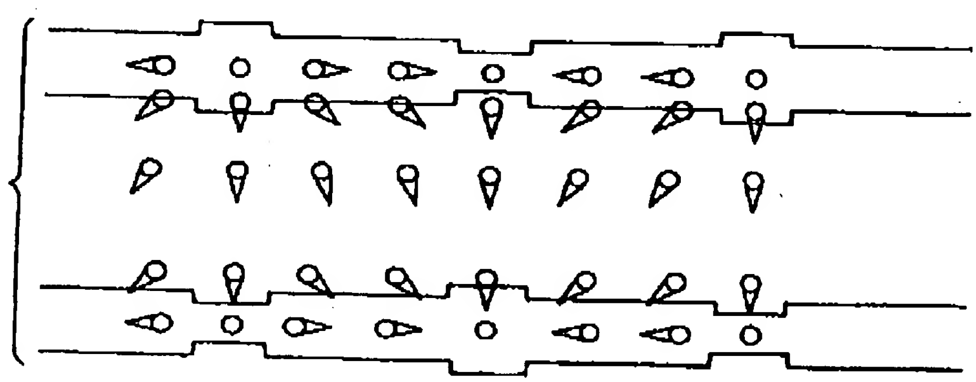
[Fig.40]



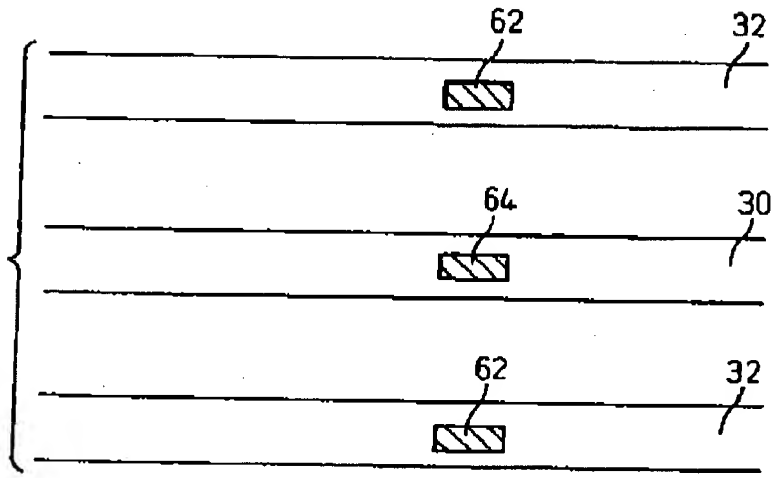
[Fig.41]



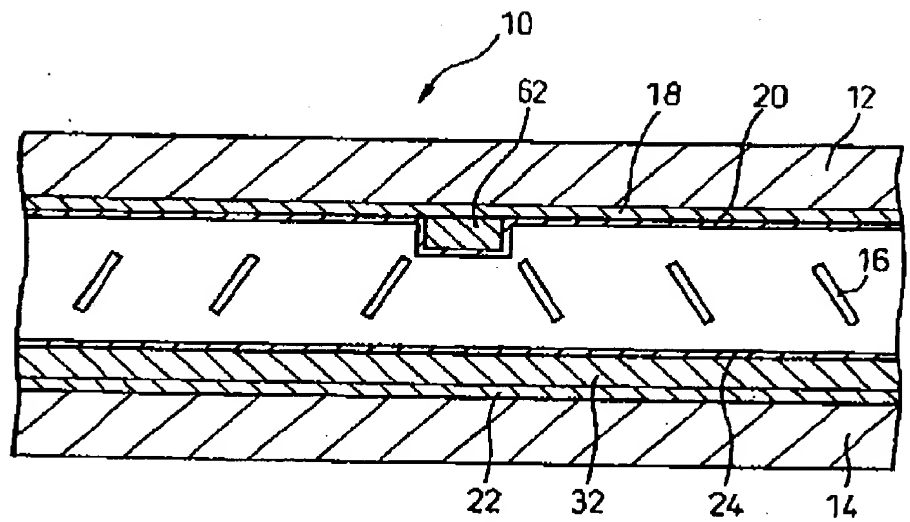
[Fig.42]



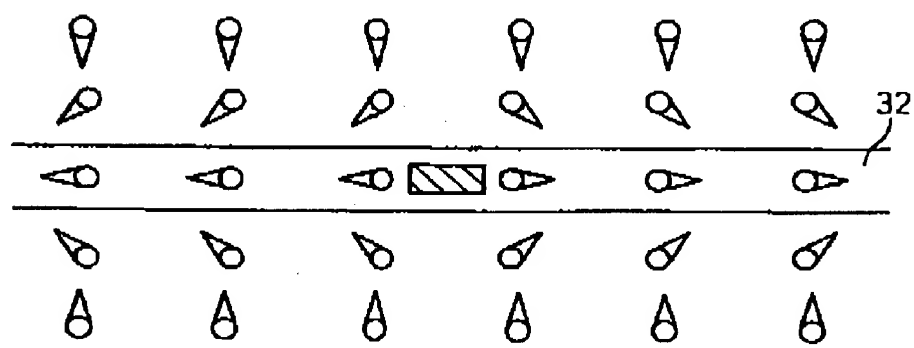
[Fig.43]



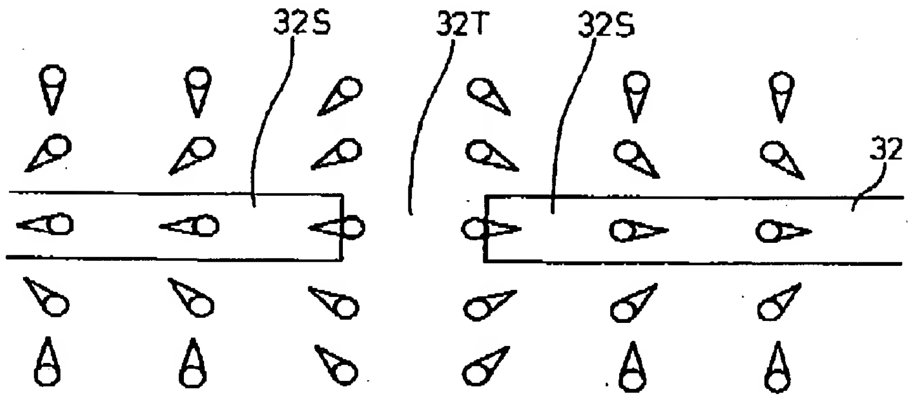
[Fig.44]



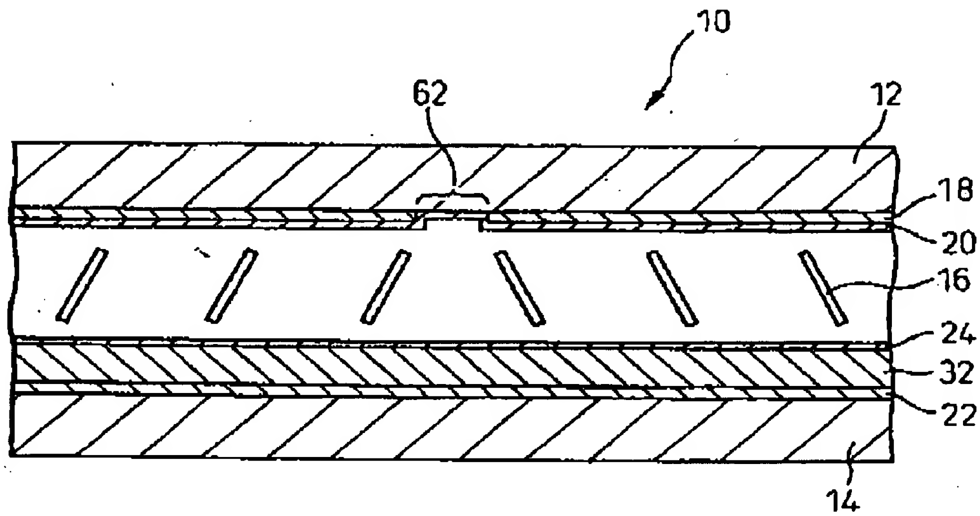
[Fig.45]



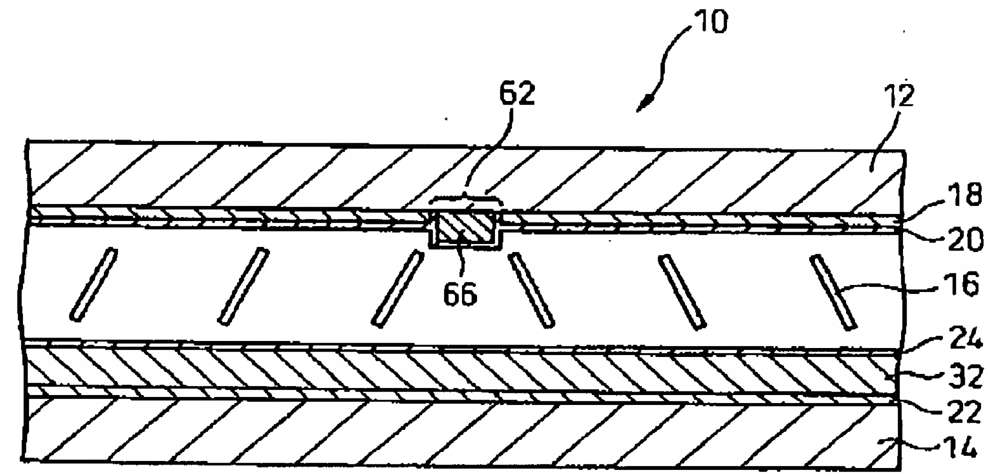
[Fig.46]



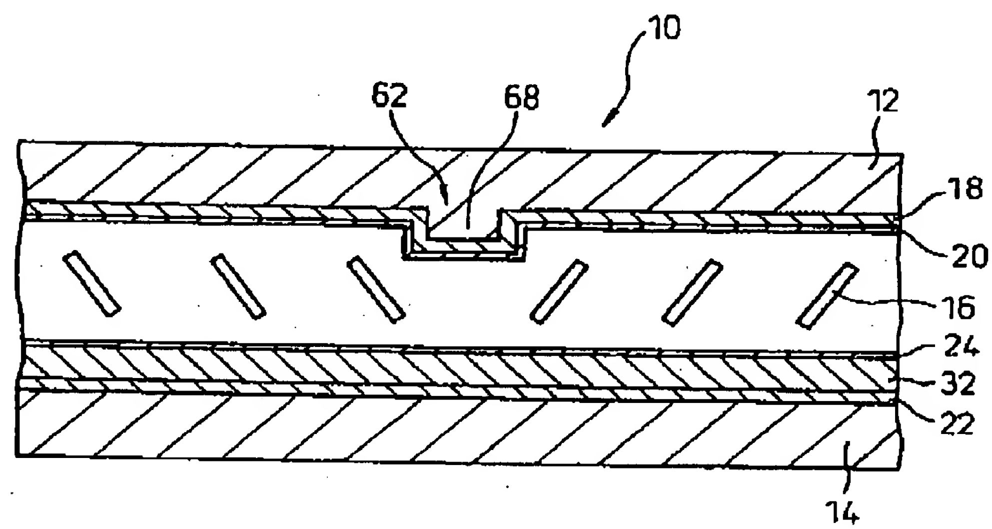
[Fig.47]



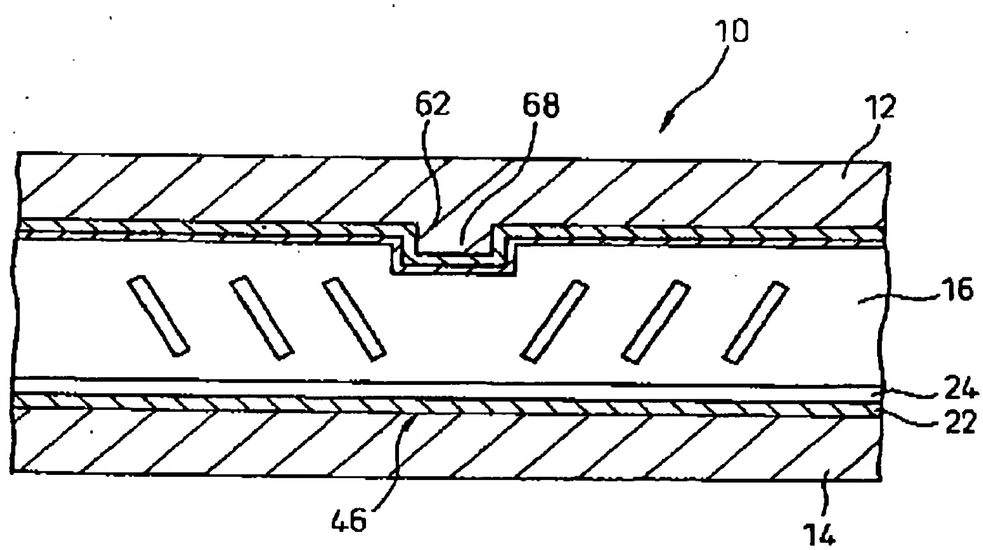
[Fig.48]



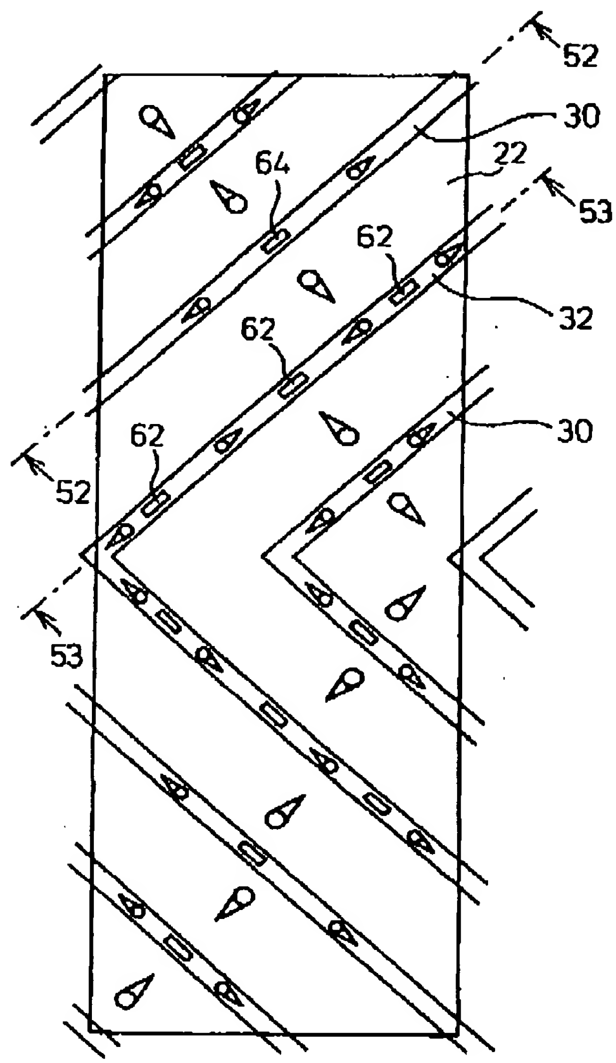
[Fig.49]



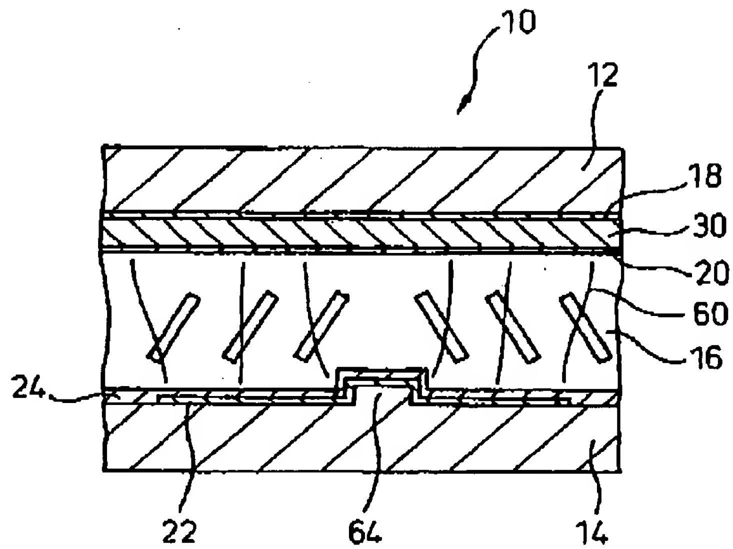
[Fig.50]



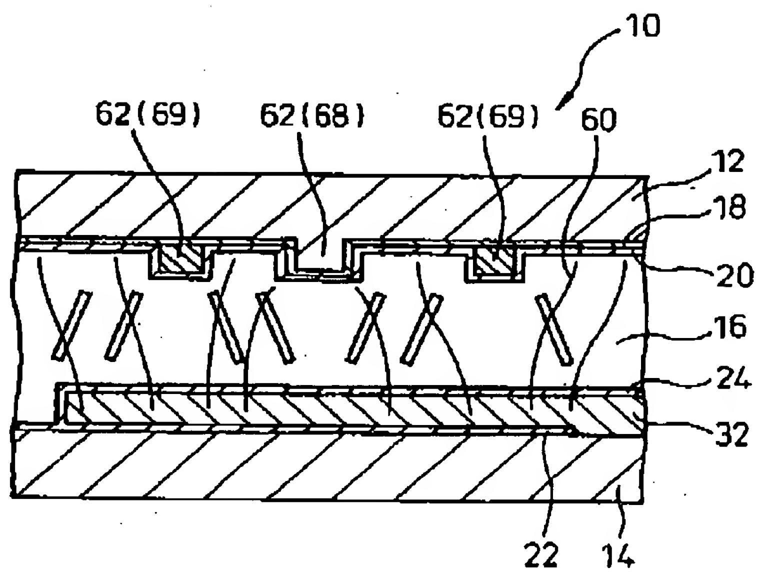
[Fig.51]



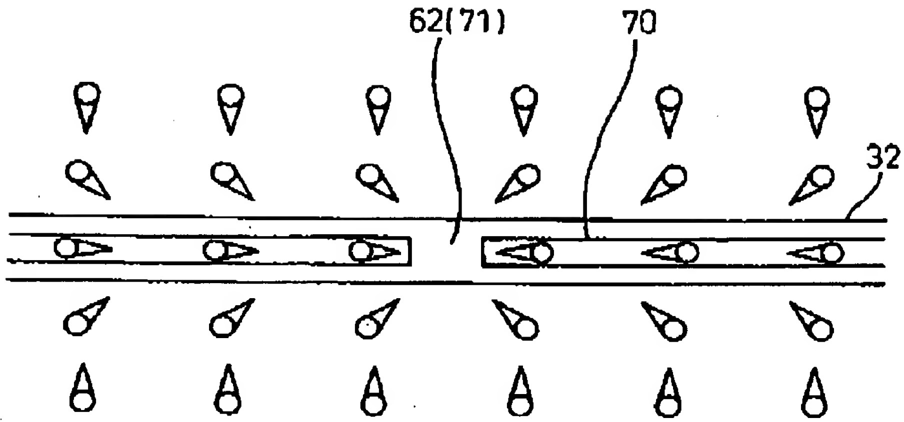
[Fig.52]


10
12
18
30
20
60
16
24
22
64
14

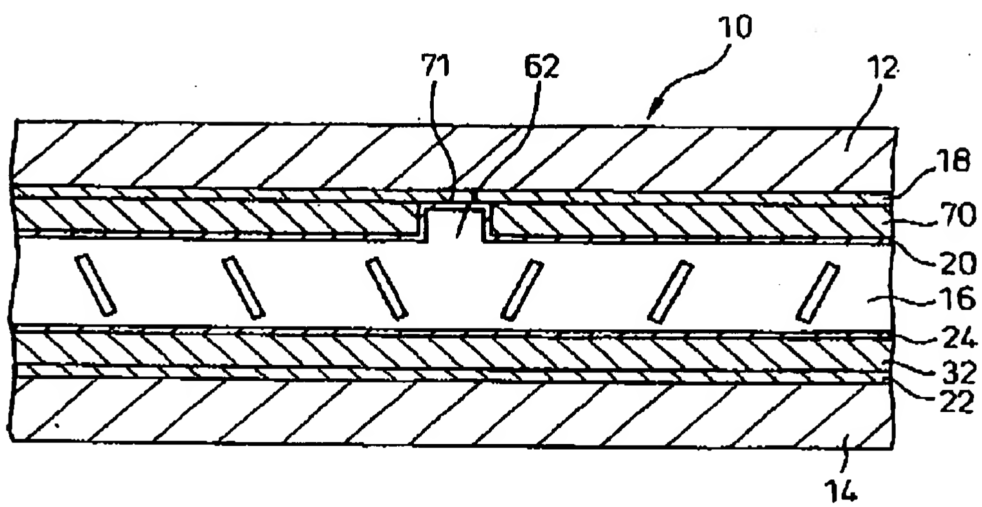
[Fig.53]


10
62(69)
62(68)
62(69)
60
12
18
20
16
24
32
22
14

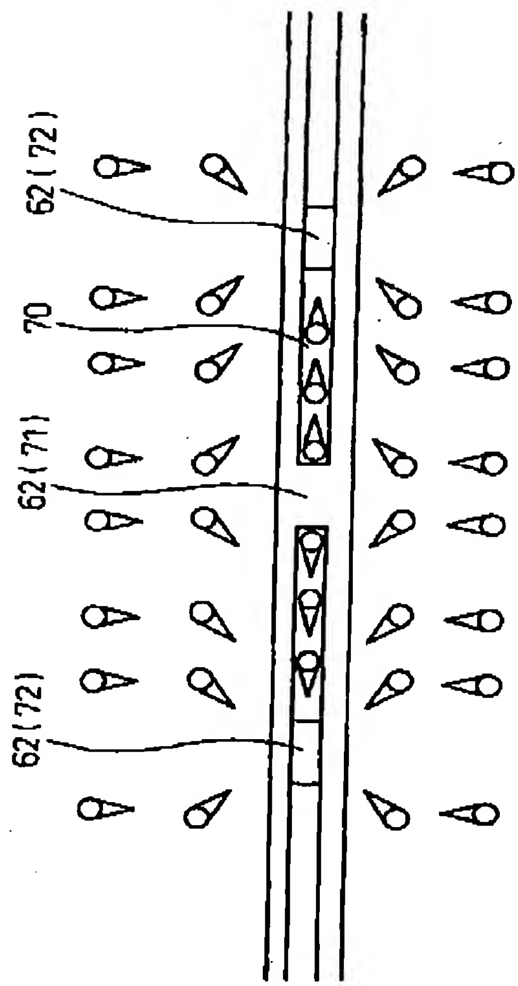
[Fig.54]



[Fig.55]



[Fig.56]



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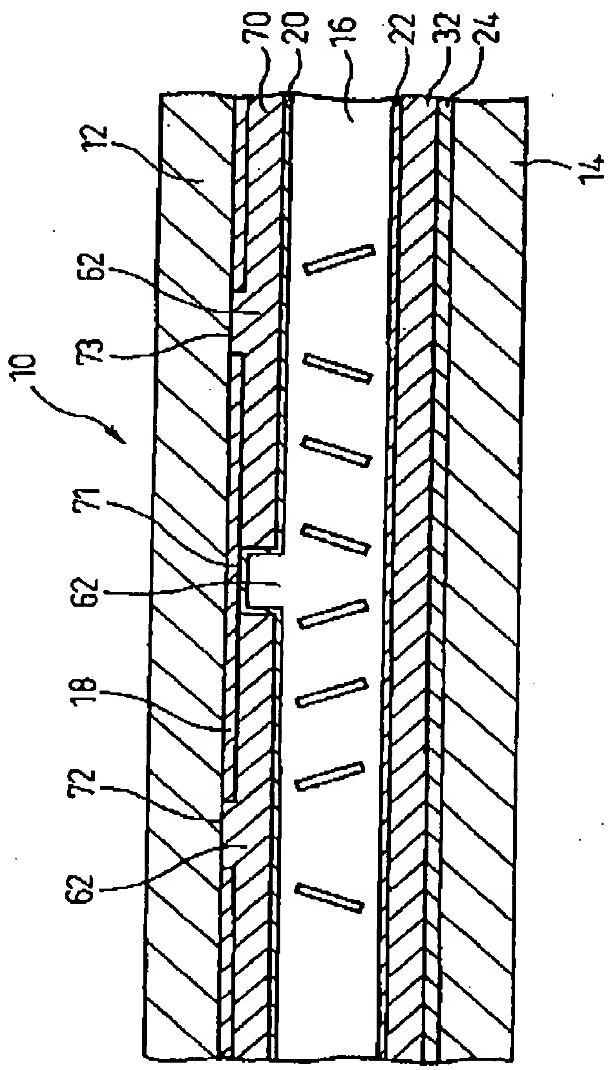
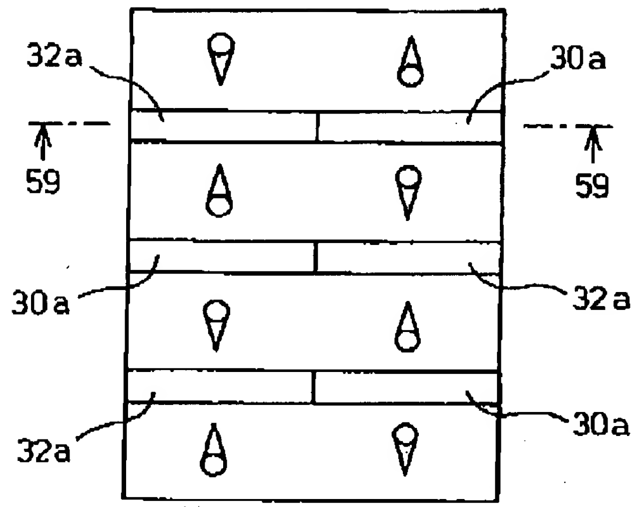
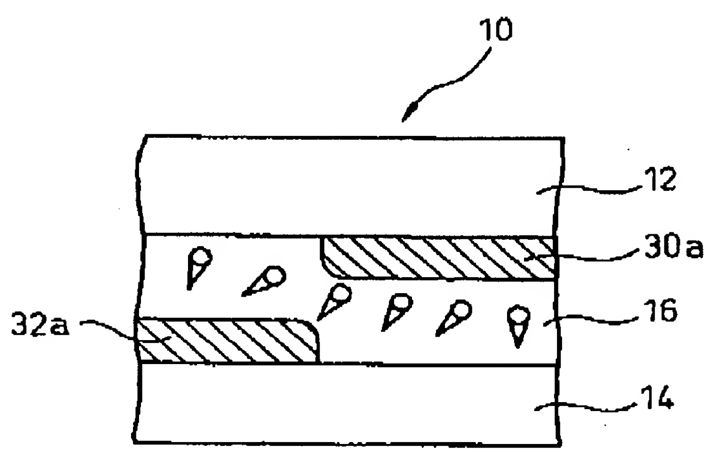
[Fig.57]



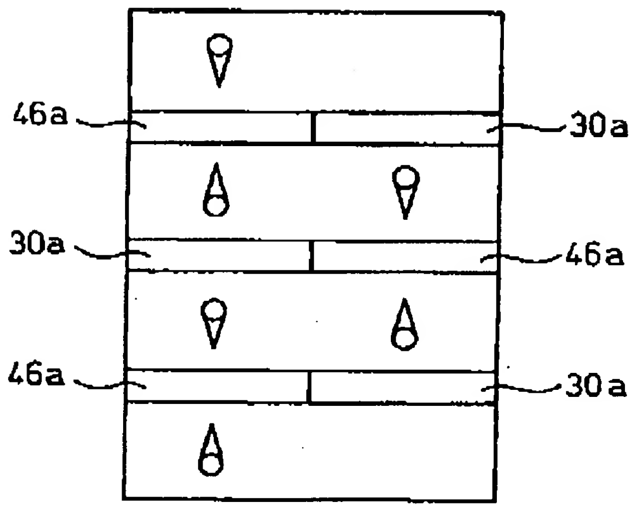
[Fig.58]



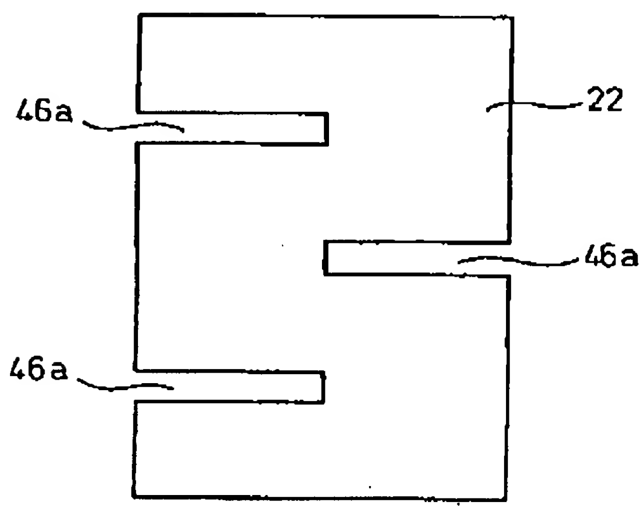
[Fig.59]



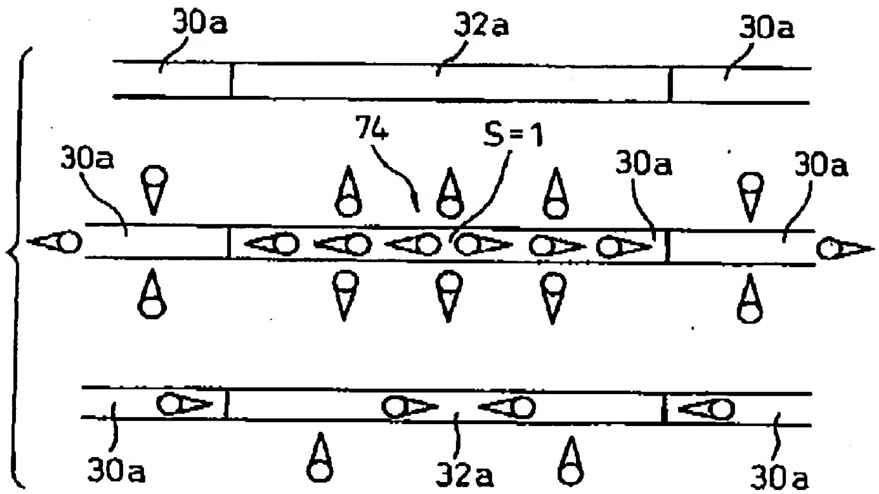
[Fig.60]



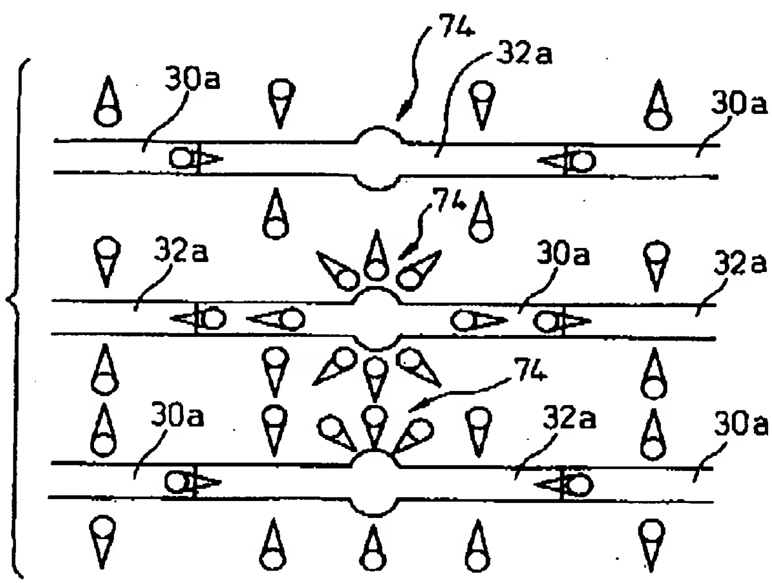
[Fig.61]



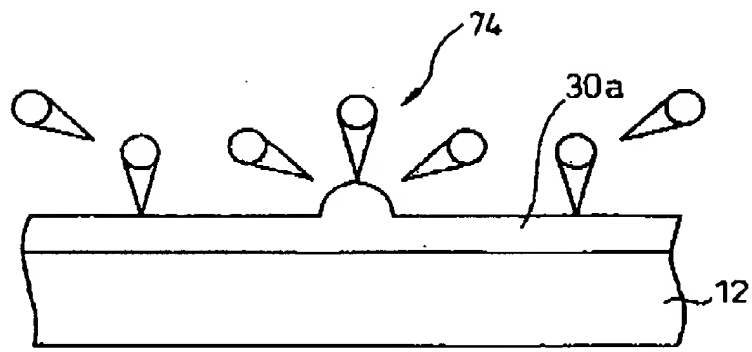
[Fig.62]


30a
32a
30a
74
S=1
30a
30a
30a
30a
30a
32a
30a

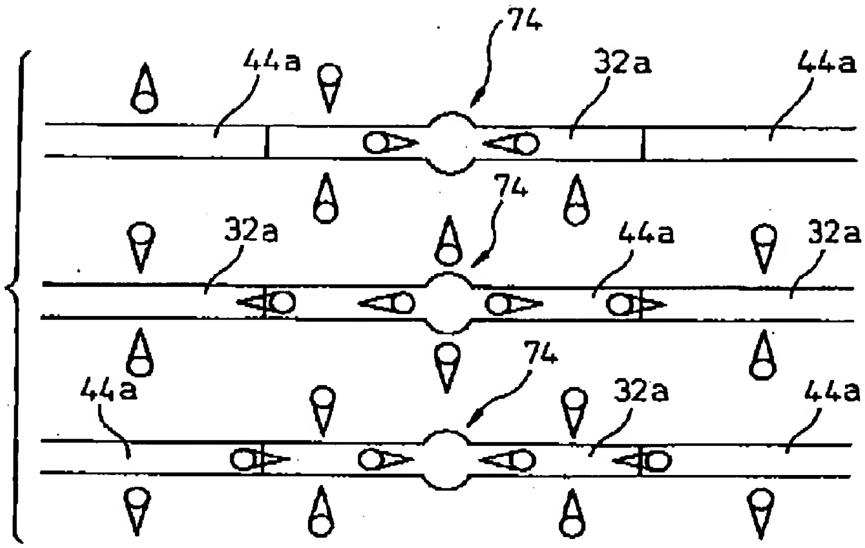
[Fig.63]


74
32a
30a
30a
74
32a
30a
32a
74
30a
32a
30a

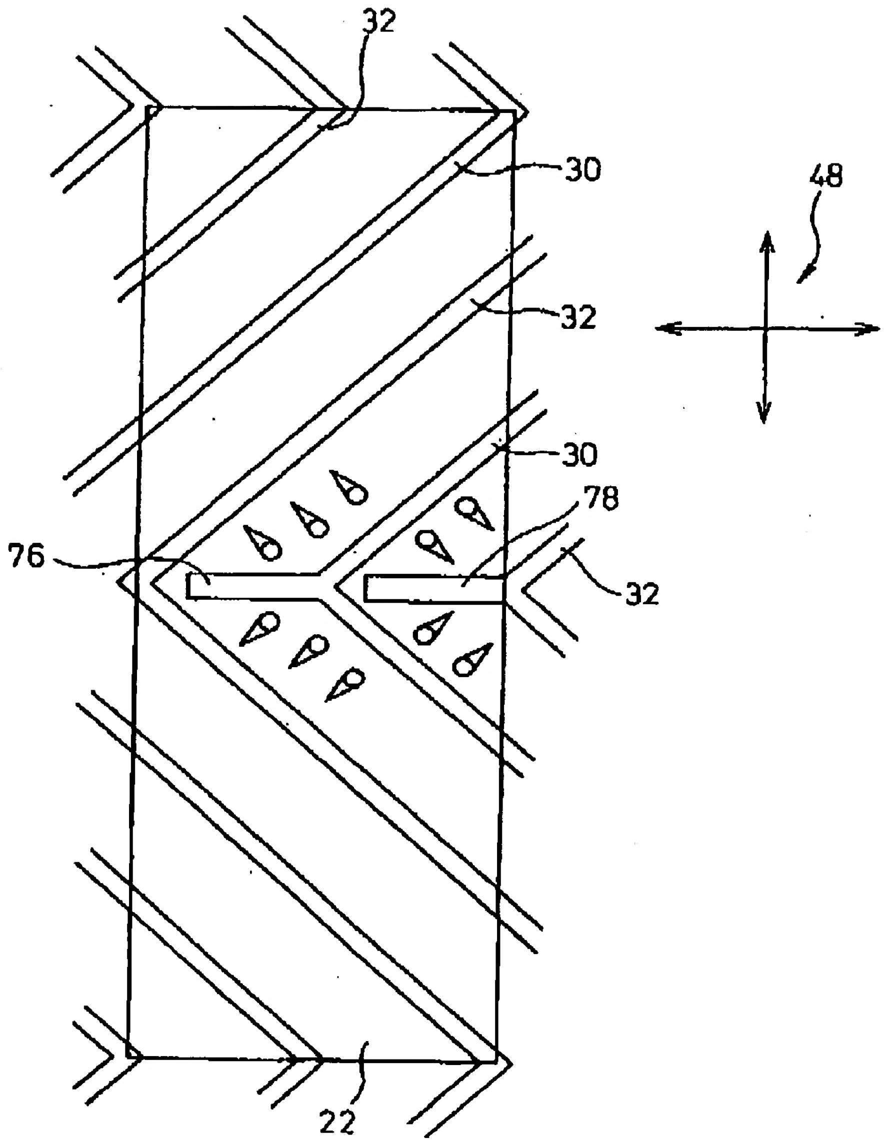
[Fig.64]



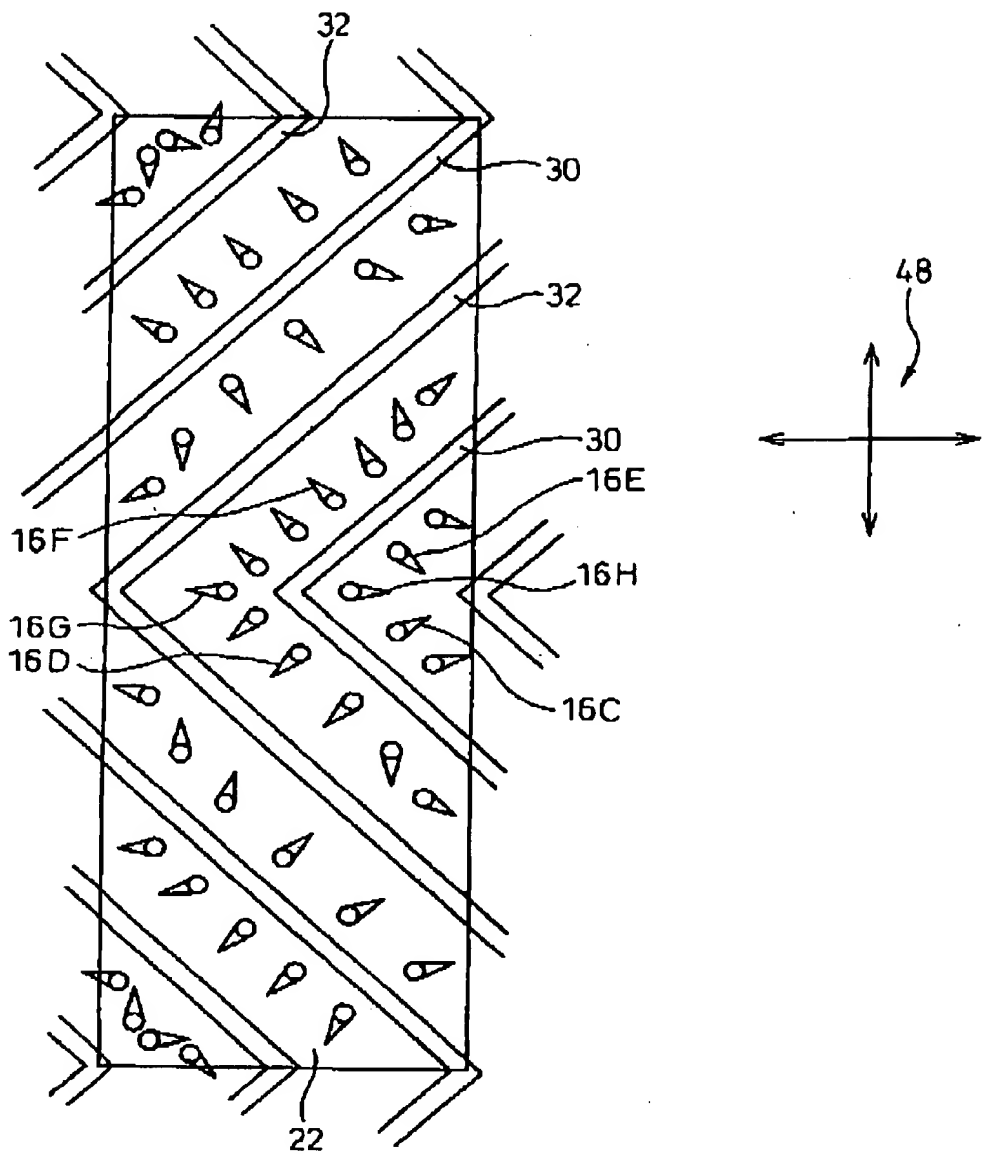
[Fig.65]



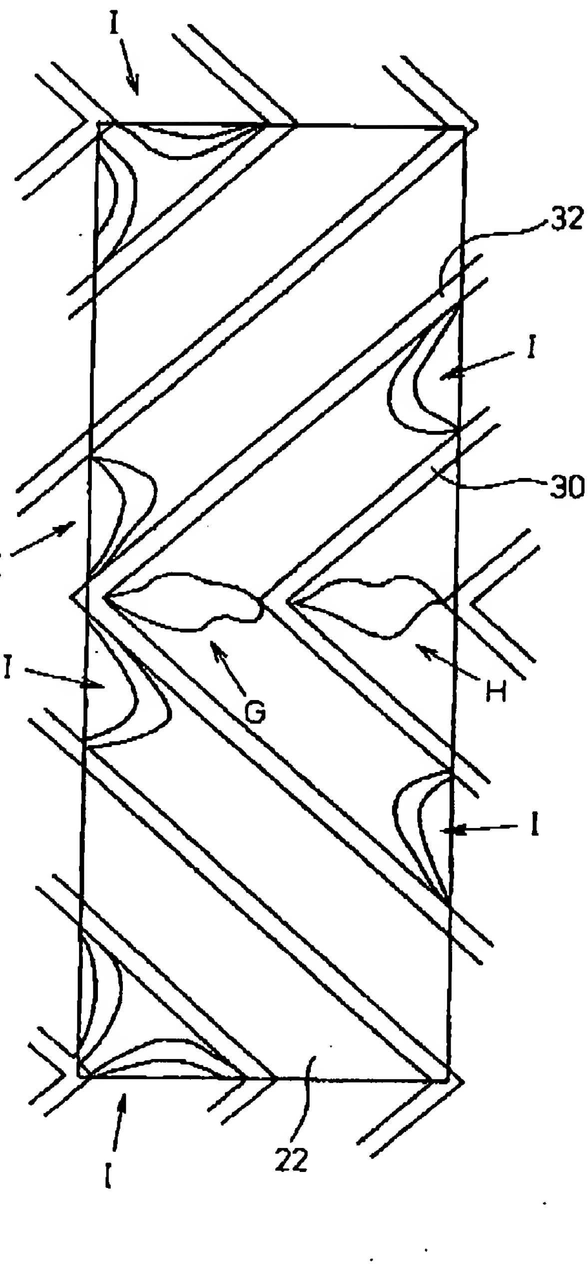
[Fig.66]



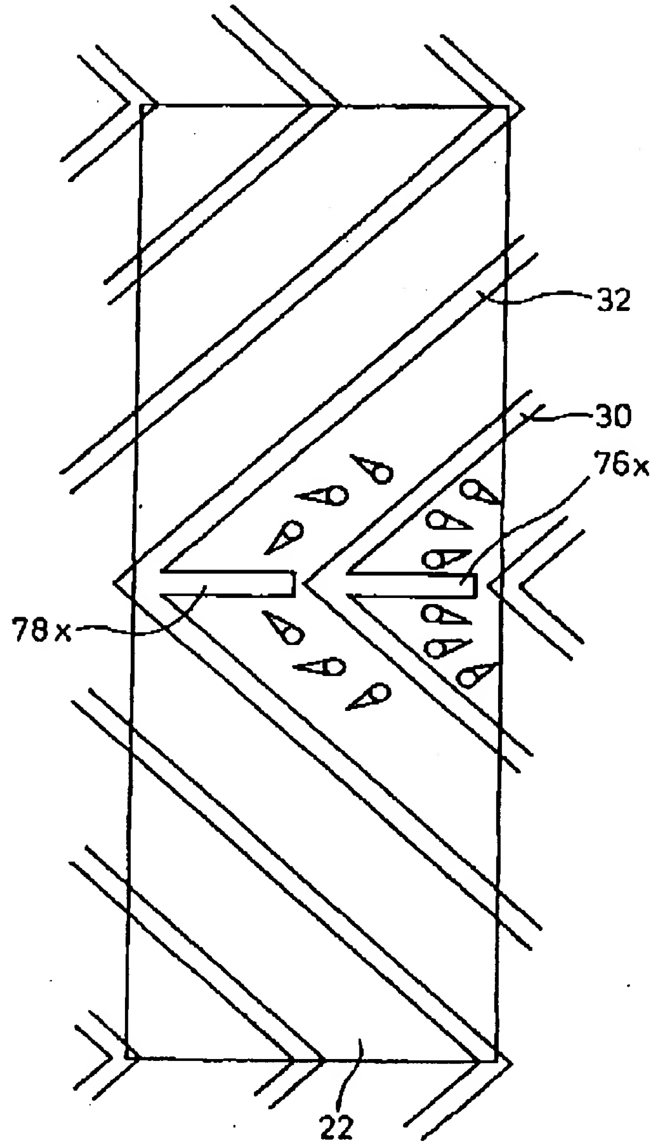
[Fig.67]



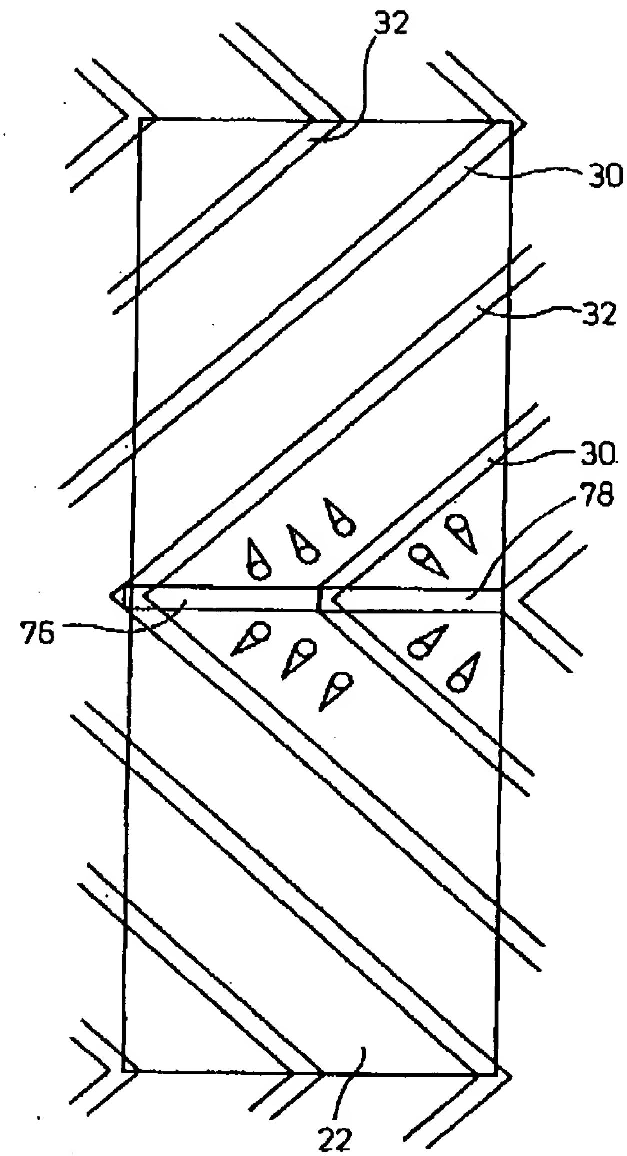
[Fig.68]



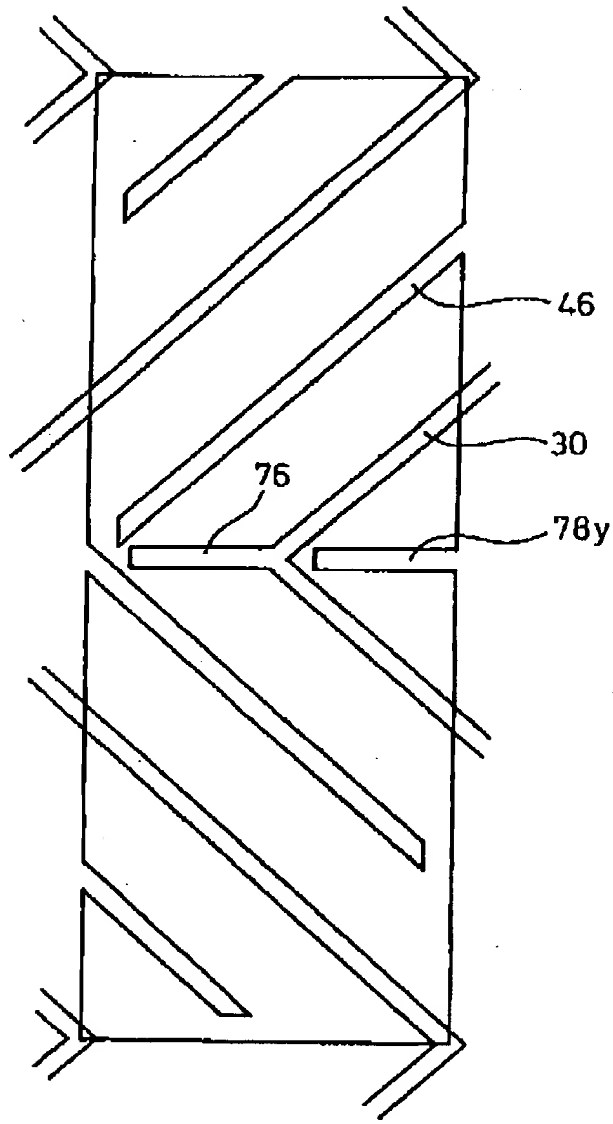
[Fig.69]



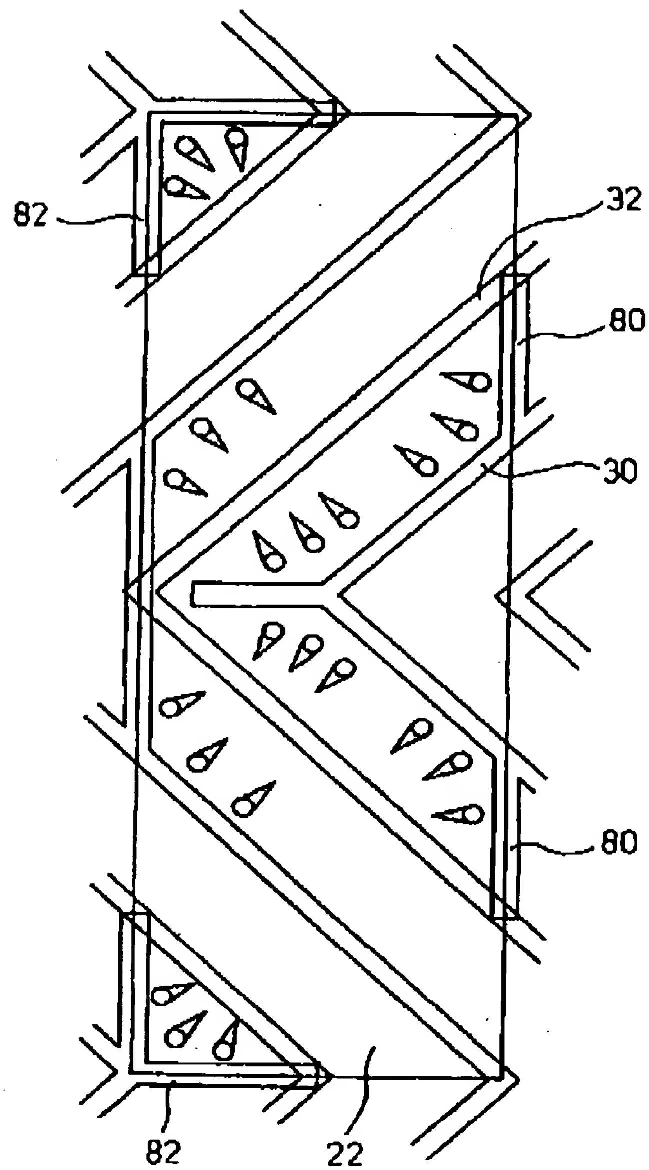
[Fig.70]



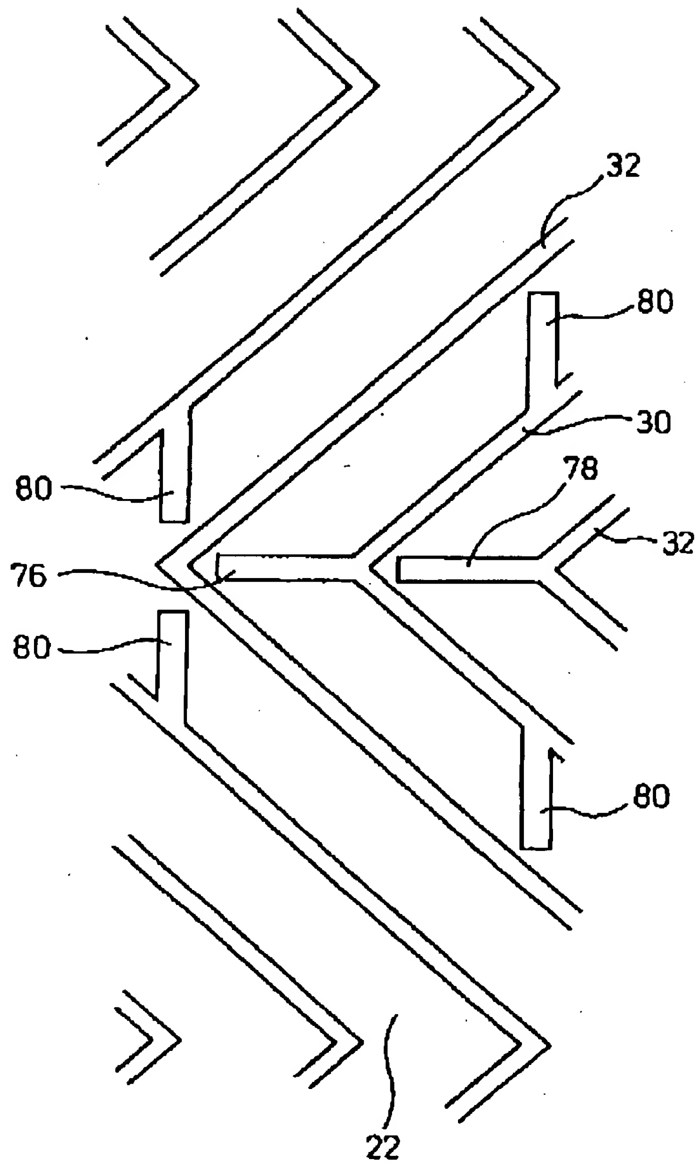
[Fig.71]



[Fig.72]



[Fig.73]



Application Number: 10-264849

[Name of the Document] ABSTRACT

[Abstract]

[Problem] To provide a liquid crystal display apparatus, or a vertical alignment type liquid crystal display apparatus, which can have further increased brightness and response speed.

[Means for Solving the Problem] The apparatus includes two substrates with electrodes and vertical alignment layers, a liquid crystal material having a negative dielectric anisotropy and inserted between the two substrates, and linear wall structures provided for each of the two substrates to control the alignment of the liquid crystal material. Each of the linear wall structures 30 includes a plurality of constituent units 30S or 32S.

[Selected Figure] FIG. 14